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UNITED STATES COMMISSIONERS

TO THE

PARIS UNIVERSAL EXPOSITION, 1867.

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EDITED BY
WILLIAM P. BLAKE,
COMMISSIONER OF THE STATE OF CALIFORNIA.

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PARIS UNIVERSAL EXPOSITION, 1867.
REPORTS OF THE UNITED STATES COMMISSIONERS.

MACHINERY AND PROCESSES

OF

THE INDUSTRIAL ARTS,

AND APPARATUS OF

THE EXACT SCIENCES.

BY

FREDERICK A. P. BARNARD, LL. D.,
UNITED STATES COMMISSIONER.

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PREFACE.

The following report is an attempt to comply with that portion of the instructions issued by the Secretary of State to the Commission of the United States to the Exposition of 1867, which required a report to be prepared upon the new inventions in the useful arts illustrated in the Exposition. It need hardly be remarked that an entirely satisfactory execution of a task like that here presented could be reasonably expected only from the co-operation of a number of individuals, severally qualified, by previous familiarity with the different departments of industry represented, to appreciate the merits of the various objects subjected to their examination. The preparation of the required report was therefore, originally, very properly confided to a committee; but the plan of a joint report, at first contemplated, was found in the end to be impracticable, and was accordingly abandoned. Some members of the committee preferred to direct their attention to the study of special subjects, and the general duties imposed on the committee devolved at length upon the present reporter alone. This statement is felt to be necessary in explanation, or rather, perhaps, in justification, of an attempt on the part of the reporter to execute a task not willingly assumed by him, and which he found no encouragement to undertake in the consciousness of special qualification.

A large portion of this report was prepared during the continuance of the Exposition, but the amount of labor thrown upon the reporter beyond the extent of his original anticipation protracted the work of its completion until after the close.

To the duties originally assigned to the committee on the useful arts was added, at a late period, that of reporting on the objects exposed in Class XII, embracing "Instruments of Precision, and Apparatus of Instruction in Science." The concluding chapters of the report are devoted to this interesting subject. A full description of the Exposition in this class would occupy a much larger space than it has been found possible, or than it would have been proper, to devote to it here. It may, however, be said generally of that magnificent display, that it was made up in great part of instruments already well known; although it is probable that there has never before been collected together in one spot so large a number of their kind, on which the highest order of artistic skill had so thoroughly exhausted itself.

It remains only for the reporter to express his indebtedness to the Commissioner General, Mr. Beckwith, for the many courtesies received from him throughout the continuance of the Exposition, and subsequently; and to bear his cordial testimony to the ability, efficiency, im-

partiality, and firmness, with which that officer discharged his always burdensome and often delicate duties; as well as to the fidelity with which he protected the interests of his countrymen, even in cases in which he knew that his services were not appreciated. This is the least that can be said to the honor of one who had more than an equal share in the common lot of men in public places of being often misunderstood and oftener misrepresented; but who, unmoved by praise or blame from interested or irresponsible sources, followed silently and steadily the dictates of his judgment and his convictions of duty, and trusted to time for that sure vindication of his course which it has at length abundantly brought.

COLUMBIA COLLEGE, *New York*, *June*, 1869.

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THE INDUSTRIAL ARTS.

CHAPTER I.

THE RELATION OF INVENTION TO INDUSTRIAL PROGRESS.

MULTIPLICITY OF MACHINES AND INDUSTRIAL PROCESSES AT THE EXPOSITION—INCESSANT MODIFICATIONS AND IMPROVEMENTS RESULTING FROM THE DIVISION OF LABOR—INVENTIONS OF GREAT INDUSTRIAL IMPORTANCE ARE RARE—EXAMPLES OF SUCH—THE COTTON-GIN: ITS INDUSTRIAL, SOCIAL, AND POLITICAL CONSEQUENCES—THE STEAM-ENGINE, AND THE INDUSTRIAL REVOLUTIONS RESULTING FROM IT—PRODUCTIVE POWER OF INDUSTRY LIMITED BY AMOUNT OF DISPOSABLE FORCE—HANDLING AND FORGING ARMOR PLATES AND OTHER GIGANTIC OBJECTS BY THE AID OF STEAM—PRECISION OF MECHANICAL PROCESSES AIDED BY STEAM—EXAMPLES OF DEGREE OF REFINEMENT OF MECHANICAL ACCURACY—WHITWORTH'S TRUE PLANES AND GAUGES—MACHINE TOOLS—INFLUENCE OF THE STEAM-ENGINE UPON THE WEALTH AND POWER OF GREAT BRITAIN—DISCOVERY AND INVENTION: THEIR RELATIONS—INVENTIONS DIRECTLY AFFECTING THE MORAL AND INTELLECTUAL CHARACTER OF THE HUMAN RACE—THE PRINTING PRESS—THE ELECTRIC TELEGRAPH—DIFFERENT CLASSES OF INVENTIONS.

The Commission of the United States to the Universal Exposition of 1867, in the distribution of its labors, allotted to a committee the duty of reporting upon the new inventions in the useful arts presented in this great industrial display. The language of the resolution appointing this committee assigned no other limit to the field of inquiry which they were instructed or at least authorized to occupy, but that which was imposed by the extent of the Exposition itself. Whatever of novelty there might be found in any branch of industry, whether in respect to the processes employed or to the instruments or implements used in conducting them, would constitute apparently a legitimate subject for their investigation.

This seemingly very comprehensive task was, however, essentially reduced by the appointment of other committees specially charged with the examination of large departments of industry, such as railroad engineering, steam engineering, metallurgy, the chemical arts, implements, machines and tools, &c., &c.; all of which may be considered as having been thus withdrawn from the attention of the committee on inventions. The field remained nevertheless sufficiently extensive; too extensive indeed to be properly explored by a few individuals, if every object presenting some feature of novelty which the Exposition embraced should be considered on that account to be entitled to their attention. In fact

with such a view of their duties, they would have found their material exhaustless, and it would have been impossible to assign a term to their labors. So vast was the variety of interesting objects, and so wonderful the diversity of industrial operations, which a common impulse had swept together into that single spot from every quarter of the civilized world, that the visitor, in endeavoring to make his way through the maze, found himself continually bewildered; and no one could leave it, after having devoted days and even weeks to its study, without feeling how imperfect had been his survey, and how inadequate a knowledge he had been able to gather of the great whole.

This will be easily understood when it is considered how large was the area over which the Exposition was spread, and how completely filled and crowded was every corner of that liberal space. The palace itself covered nearly forty acres of ground; and the park, with the broad enclosure on the shore of the Seine, embraced about eighty acres more. To this must be added the fifty acres of the island of Billancourt. In many portions of the palace the objects on exhibition were too numerous for the space allotted to the exposants, and permission had been sought and obtained to occupy with the more bulky or the more showy the space in the avenues and passages, to such an extent as considerably to obstruct circulation. The number of exhibitors exceeded fifty thousand. A visitor who should have desired to distribute his attention impartially among all these candidates for his approbation, would scarcely have been able to give to each more than the most cursory glance. The gates were opened every morning at eight o'clock and closed every evening at six. By giving a single minute to each exhibitor, and by employing faithfully all the intervening time, it would have been possible to dispose of six hundred in a day. But even at that rapid rate, it would have taken three months of unintermitted labor to complete the list. Many of these exhibitors, moreover, presented not single objects, but scores and hundreds. There is no extravagance at all in the assertion that the number of objects in the Exposition, each individually interesting and worthy, if time allowed, of a separate examination, amounted to several millions. In such a scene the attractions and the distractions are so equally balanced, that it is only after the observer has resigned himself to the necessity of passing by the greater number without an attempt at a critical notice, that he is prepared to form an intelligent judgment of those that remain.

If, again, in the study of such a multiplicity of industrial processes or machines, he endeavors to make a distinction between what is justly entitled to be called original and what is familiar and common, he finds himself arrested by a new embarrassment. There is no form of industry which, in our day, is stationary for a moment. There is none which is not undergoing improvement so incessant that even while the history of the most recent advances is being written, they are beginning already to be numbered with the past, and giving place to improvements newer

still. This is peculiarly the case in those great branches of industry which require for their successful prosecution the concentration of capital and the systematic division of labor. The division of labor is a practical analysis of the industrial problem into its most elementary parts; and the distribution of these parts to as many individuals brings the force of many minds or groups of minds to the study of the question of improvement under the most advantageous conditions. It is true that many workmen pursue their daily task in a manner entirely mechanical, without considering whether or not it might be accomplished in a better or a simpler way; but it is also true that the most useful modifications of many industrial processes and machines have been the suggestions of the men employed in using them, and have been the fruit of their personal experience and observation. It is further true that in large industrial establishments there exists always a facility for testing the advantages offered by a newly suggested implement or process, which does not exist elsewhere; and that therefore a new invention, if brought forward in such a field, will not have long to wait, that its merit, if it has any, may be recognized. And thus it happens that in such establishments rarely a day, and certainly never a year passes, in which successful ingenuity does not make some addition to productive power, by giving to its instruments increased efficiency, or to its products a superior quality.

Such being the case, there cannot be a great industrial congress, like that assembled in the Exposition of 1867, which will not be full of what may in one sense be called new inventions; but of these the great majority will have for their basis some industrial process or machine which is not new, but is common to the entire branch of industry to which they belong. The textile arts, for example, employ a larger variety of machinery than any other, or, at least, than any other whose processes are capable of being fully exhibited in a place like the Exposition and under the eye of the public; yet, it may be said, generally, that the processes by which fibrous materials are prepared for the spindle or the loom are substantially the same now in kind and in order as they were in the earliest period of history, and when the art was in its most rudimentary condition. But the modes and instrumentalities by which these changes are produced have been so completely transformed that in its present condition the art would be totally unrecognizable by one who had known it only under the slow forms practiced by the Romans or the Egyptians. These transformations have been the offspring of a few great inventions, of which each in its time has marked an era in the history of this industry. But it is in the nature of great inventions that they narrow the field of activity to future ingenuity; and that while they may admit of subordinate modifications and improvements, they are but tardily, if ever, dethroned by successful rivals. Much the larger number, therefore, of the novelties in industrial art which each year introduces consists of these minor improvements; and to make an exhaustive enumeration of such, as they appear in a general exposition

of the industries of the world, would involve the necessity of descending to an endless minuteness of detail. An observant visitor to the gallery of the Exposition devoted to the useful arts, who should have carefully compared, for instance, the various machines in use for the manufacture of cotton, would have noticed that, while each exhibitor employed for the same operation substantially the same mechanical contrivance, yet nearly every one also claimed some peculiarity in the details of construction as original with himself. The observer would have, perhaps, been still more forcibly impressed with the evidence of this truth in looking through the magnificent collection of objects which modern ingenuity has so wonderfully multiplied, under the name of machine tools. The differences might strike him as larger than in the former case, but he would still observe the same general form and substantially the same modes of operation, though with many variations in the manner and succession of movements and in the relative position of the tool and the material operated upon. Another illustration might be found in the important art of printing. Since the origin of this art in the memorable invention by which impressions were first taken from movable type, its history has been marked by a number of transformations in the mechanical part of the process so signal as to form each for itself a new era. One of these was the introduction of the power press and the substitution of the cylinder for the platen, and another was the transference of the form from the horizontal bed to the cylinder and the suppression of the reciprocating motion. By each of these improvements there was effected almost as large an advance in the power of multiplying impressions beyond what had been before possible as had been attained by the original press of Gutenberg over the slow process of transcription. But in the intervals between these great steps of advancement the printing press underwent innumerable minor alterations and improvements, many of which tended greatly to increase its efficiency and to improve the excellence of its work without, nevertheless, changing its essential character or making of it a new, although they made it a better, machine. In the recent and familiar invention of machine-sewing we have still another exemplification of the same distinction. The germ idea successfully embodied in the original machine was one of immense value; the numerous modifications which the mechanism has since undergone—every detail having been made the subject of half a dozen patents at least—have had a value only relative and secondary. And though in some instances the ingenuity of inventors has devised mechanical combinations essentially original for performing the same work, the success, however mechanically interesting, is without striking industrial importance, since it accomplishes no new result.

If we attend to the current history of invention we shall observe that much the larger number of the contributions to industrial advancement which present themselves in the form of new processes in the arts or new adaptations of mechanical principles to manufacture are of the secondary

and relatively unimportant class above distinguished. But what each single invention may lack in its separate importance is amply compensated by the combined value of the immense number which are continually and simultaneously originating. The general growth of productive industry in the world is, consequently, nearly uniform and steady. At distant intervals there may occur a sudden swell in the wave, in consequence of the appearance of one of those rare inventions which are destined to give to some great branch of industry an entirely new character, or whose stimulating influence makes itself felt throughout all industries; but the current never sets backward, and whatever is gained from each of these extraordinary impulses remains a permanent acquisition.

To illustrate by example the nature of these occasional and singular impulses, we may refer to the consequences which have followed from the invention of the cotton gin. So long as no better mode had been thought of, of separating the seed of the cotton-plant from its accompanying fibre, but that of picking out each seed by hand, there existed a natural and entirely effectual obstacle in the way of making this valuable material the basis of a great manufacture. Whatever might be the demand, there was a physical limit to the supply. There can, of course, be no doubt that it was the demand which enlisted ingenuity in the endeavor to overcome the obstacle, and to make an increase of the supply a possibility. It was, therefore, the demand which produced the machine. And it is, accordingly, no injustice to the ingenious inventor to whom we owe it, meritorious as we admit him to have been, to say that had he not turned his thoughts in this direction, nor devised this particular mechanical contrivance for performing a work of which the world had so pressing need, some machine, in all material respects equivalent to this, must have made its appearance without any long delay. Of the many minds then directed toward the solution of a problem of so vast importance, though none, indeed, yet perceived how vast, some one, or perhaps more than one, must have resolved it successfully, had not the opportunity been taken away.

But if it is correct to say, on the one hand, that the demand produced the machine, it is no less true, on the other, that the machine stimulated the demand to a most extraordinary degree. From the insignificant amount of 150,000 pounds of American cotton received in England in 1791, the exportation to that country rose in ten years to 15,000,000. At the same time, the practically unlimited extent of soil adapted to this culture on the American continent made it evident that the demand might grow to any extent without producing a corresponding increase of price, or even with an actual reduction. Such a supply of a material capable of being wrought into the largest variety of textile fabrics could not but stimulate the introduction of numerous and signal improvements into all the processes of manufacture. Thus the creation of the automatic machinery by which the production of cotton fabrics, early within this century, rose to a hundred-fold what it had been at the close of the last,

and by which, in the year 1860, it had been brought to a thousand-fold at least, was a direct consequence of the invention of the cotton gin. Nor was the influence of this invention confined exclusively to matters of industrial or economical importance. It affected profoundly the social condition of multitudes in both hemispheres, and in one of them involved very grave political consequences. But for the increased and constantly increasing importance of cotton to the industry of the world, those of the American States which were fitted by soil and climate to the production of this plant would not have neglected every other industry in the pursuit of this alone, nor have become rooted in the belief that compulsory labor was essential to their prosperity. And had it not been for this belief, and for the discordance of views which grew out of it between the cotton-producing States and the other members of the American Union upon matters, both political and moral, of vital importance, the terrible convulsion which has recently shaken the Union to its centre could never have occurred. It is at once curious and interesting to trace a connection between two events so widely different in character and so widely separated in time as the great rebellion of 1861 and the invention of the cotton gin; yet, from what has just been said, it is obviously admissible to regard these two events as standing to each other in a certain sense in the relation of cause and consequence; and though the great national disaster just mentioned may have been immediately precipitated by causes much less far to seek and much more easily recognizable, still, at the distance of two-thirds of a century, the connection just hinted at is to the eye of the political philosopher not the less clearly discernible. In this proposition it is not intended to assert that the rebellion would not have occurred if the invention had not been made. It has been remarked already that the time had arrived in the world's history when the cotton industry, in obedience to the law of industrial advancement—a law as constraining as that of organic development—was destined to receive a large expansion. If the machine which, in point of fact, was instrumental to the fulfilment of this destiny had not presented itself, some equivalent form of mechanism must have done so; so that the way would have been opened for the entrance of a train of moral and political consequences in all essential respects resembling those which it has been our misfortune to witness. It would be wrong on this account to infer that any great industrial improvement, whatever the temporary or local evils of which it may be the occasion, can ever be a real calamity to the human race. The remarks here made are intended only to illustrate the degree to which a single invention may often influence the destinies of nations. Whether this influence shall be wholly good or wholly or partially evil will often depend upon the pre-existing state of human society, in the midst of which the invention has its birth. To the world the benefit which has resulted from the vast development which the cotton manufacture has received within the present century is great beyond

the power of calculation; to a portion of the world, long more than equally a sharer in the benefit, it has proved for the time a source of bitter evil. If in making up the account we have to consider both results, it is due to the cause to credit it with all the benefit as its proper and legitimate offspring, while the evil must be charged to the unnatural condition of society which this cause only tended to perpetuate.

The industrial revolution which followed the invention of the cotton-gin was confined to a single, though an extremely important, branch of industry. In some rare instances an invention has appeared whose wider relations to the means of production have extended its influence to many industries at once, and even ultimately to all industries. Such an example presents itself in the case of the steam-engine. Before the introduction of this machine, all heavy industrial operations were effected by the muscular force of men or animals, aided, where circumstances permitted, by the power of running streams. The winds were laid under contribution for certain lighter industrial tasks; but it needs very little reflection to perceive how limited must have been and must always be the range of their usefulness. The productive power of any industry must always be limited by the amount of force disposable for its purposes. While the only considerable force, except that of animals, at the disposal of man was the force furnished by falling water, it is obvious that all great industrial operations were confined of necessity to certain localities. No great factories, no great foundries or rolling mills for iron, no great flouring-mills for grain, could exist except in those rugged districts through which the mountain torrents make their way to the lowlands or the ocean. The broad and level tracts which form so vast a proportion of the habitable continents, and which by their fertility are adapted to sustain the densest population, could have no part in these great industries. Nor was it a slight inconvenience that, as a general rule, the power and the material on which it was to operate were not to be found on the same spot. As the power did not admit of transportation, it was necessary to carry the material to it; a necessity involving much loss of time and labor, and no slight expense. The transportation to great distances of raw material, though in the existing state of many industries it is often necessary, is attended with great and obvious disadvantages which it is desirable to avoid. The part of this material which becomes ultimately utilized in the manufacture, constitutes in many cases but a small proportion of the entire weight, and perhaps a less proportion still of the bulk; so that the greater portion of the expense of transportation is paid for the moving of substances which are not only useless, but which must be got rid of before the remainder can be useful. These are disadvantages under which all grand industries labored while dependent upon water-power alone. Nor were these all, for it is probable that in some branches, at least, they could never have reached their present development, had they continued to be always so dependent. For the highest uses of industry, it is not enough to have

at command a great amount of power; it is also indispensable to be able to concentrate it upon occasion within small space. In the British and French departments at the Exposition may be seen armor-plates for ships originally rolled from twenty to thirty feet in length, from three to six feet in breadth and from eight to thirteen inches in thickness. The force required to drive these masses through the rollers from which they receive their form, could hardly be conveniently obtained from a water-power. Moreover, the massive hammers now required to forge the huge masses from which these plates and other gigantic objects are formed would be wholly unmanageable without the use of steam.[1]

The steam-engine not only does the work of water equally well, but it does it equally well under every variety of circumstances. It furnishes power in any amount that may be required, and in any place. If a raw material is to be manufactured, the power may be set up where the material is produced. Place it in the forest and it will reduce the trees to the form of lumber for the market; or, if more is exacted of it, will mould them to finished forms ready to be united by the cabinet-maker or

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[1] While the Exposition was still in progress, Sir John Brown, of the Atlas Iron Works, Sheffield, England, caused to be rolled a plate surpassing in dimensions even the largest of the immense masses above spoken of; its length being twenty feet, its breadth four feet, and its thickness *fifteen* inches. Even this extraordinary achievement by no means exhausts the power of the mills or the capacity of the furnaces; but plates are rolled no larger, only because larger plates have not been demanded, and because no floating battery could carry them. The scene presented in the Atlas works, at the time of the rolling of this huge plate, is vividly described by a correspondent of the London Times who was present on the occasion. It is quoted as furnishing a most striking illustration of the extraordinary change which the steam-engine has wrought in the most important of the world's industries:

"The plate was not quite ready at the time appointed, and during the short interval of delay the works were inspected. It is almost impossible to describe the aspect of cyclopean activity which they presented The huge space of lofty workshops, covering more than 23 acres of ground, were, above, all dim with smoke; below, all dazzling with the blinding glare and heat of furnaces. Everywhere ponderous fly-wheels were spinning round with a loud hum through the gloom, everywhere steam-hammers were falling with a shock upon the solid earth that made the walls vibrate, and people near them jump under the tremendous concussion. No place seemed free from steam or flame or melted iron. The dark nooks would suddenly become bright, as furnace doors were lifted and emitted their long light-looking flames of dazzling white vapor, and disgorged a mass of seething metal, which men, almost clad in light steel armor, wheeled away and shot under the steam-hammers, the first stroke of which sent jets of melted iron rushing in trains of fire like meteors in all directions. Sometimes one came on groups of men who were saturating in water the rough bands of sacking in which they were enveloped before going to wrestle with some white-heat forging, sometimes on men nearly naked, with the perspiration pouring from them, who had come to rest for a moment from the puddling furnaces, and to take a long drink of the thick oatmeal and water, which is all that they venture on during their labor, and which long experience has proved to be the most sustaining of all drinks under the tremendous heats to which they are subjected. On every side the glare, the smoke, the din, and steam are alike deafening and blinding. On every side are masses of melted iron running down troughs, or great blocks of it heated to a glow that is almost melting being welded and knocked away in myriads of sparks and jets of refuse under the blows of the hammers· Most uncomfortable of all are the slabs of armor-plate and blocks of steel ingots which, half cooled, and of a dull slate color, lie about everywhere. From those in a bright, red glow, the visitor can guard himself, for he sees them; but from those which are partly cooled, but

the joiner. Place it by the side of a quarry, and it will convert the rude blocks of marble disengaged by the workmen to geometrical shapes, suitable to be laid in the walls or to adorn the interior of a palace. In the mineral region it offers its services to the metallurgist in every branch of his difficult labor. It blows for him the bellows, it lifts the heavy hammer, it turns the powerful lathe, it drives the steady tool of the plane, it crushes between resistless jaws the fiery masses which are to form the iron ways of our railroads, or the ponderous walls of our floating batteries. In a country favorable to the textile arts, it performs with incredible rapidity and facility all those operations which for so many centuries were accomplished by the slow and painful labor of human hands, separating the useful fibre from its impurities, loosening its entanglements, preparing it for the spindle, drawing it out into threads, and finally weaving it into fabrics of endless variety and beauty; performing, also, all this work equally well upon a hundred looms at once, or upon a single one.

Besides this, the steam-engine presents itself as a ready helper in all

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yet hot enough to scorch the flesh from the bones when closely approached, there is little safeguard, as one hurries out of the way of seething puddle blooms or open furnaces, which diffuse such an intense general heat around that little extra warning is given by the treacherous masses of half-cooled slabs till the danger is almost too near to be avoided. After seeing and suffering under seeing such scenes, the visitors were conducted to the armor rolling-mill, where the monster plate was to be drawn. The process of drawing it is simple, but peculiar. The plate, when laid in the furnace, rests upon little stacks of fire-bricks, so that the flame and heat plays equally round it, till all is glowing white, and the successive layers have settled down into one dense mass. A great deal of the success depends upon the time at which the plate is drawn and the amount and length of time to which it is to be heated. All this is regulated by the chief roller and chief furnace-man, who are paid wages which many eminent professional men might envy—wages amounting from 1200*l.* to sometimes 2000*l.* a year. On Friday, as the time for 'drawing' approached, these officials opened the furnace doors, and, approaching close to them with only the shelter of a lump of wet rag held loosely before their arms and faces, peered into the blinding glare from time to time with as much care and apparently as much indifference as if they were looking into the tube of a telescope. Suddenly, at a signal from the furnace-man, the bands of workmen, to the number of about 60, arranged themselves on each side of the furnace, as near to it as they could bear the heat. Then the doors were opened to their fullest, and what had been a glare before and what had been a heat were quite eclipsed by the intense light and fervency with which the long tongues of flame leapt forth. In the midst of this great light lay a mass even whiter than the rest. To this some half a dozen men drew near. They were all attired in thin steel leggings, aprons of steel, and a thin curtain of steel wirework dropping over their faces like a large, long visor. All the rest of their bodies were muffled in thick wet sacking. Thus protected they managed, with the aid of a gigantic pair of forceps slung from a crane above, to work as it were amid the flames for a few seconds, and to nip the huge plate with the forceps. The signal was then given, and the whole mass of iron, fizzing, sparkling and shooting out jets of lambent flame, was by the main force of chains attached to the steam rollers drawn forth from the furnace on to a long wrought-iron car. The heat and light which it then diffused were almost unbearable in any part of the huge mill, but the men seemed to vie with each other to approach and detach the colossal pincers which had drawn the iron forth. More than a dozen attempts were made on Friday before this was effected, and more than a dozen of the best and most skilful workmen were driven back one after another by the tremendous heat and glare. At last all was made clear. The forceps, then red-hot from their grip of the plate, were drawn away, the chains cleared from the rollers,

the minor industries, which, until its introduction, had no resource but that which was afforded them in animal power. The turner, the wheelwright, the carpenter, the joiner, the locksmith, the brass-founder, the lapidary, the printer, the optician, the confectioner, the baker, the agriculturist, may now accomplish the most laborious part of their several tasks, with only the personal exertion on their own part which is necessary to superintend, and, from time to time, to guide the work of the tireless assistant which they find in the steam-engine. In agriculture the advantage which the engine is capable of affording is but recently beginning to be realized, but already its use is all but universal in England, and is becoming general in our own country, in threshing out the grain crop; and it is beginning to be successfully employed in driving the plough and the cultivator. A single English engine-building house sold, in 1852, two hundred and forty-three portable engines for farms, representing a horse power of 1349; in 1862 the number was more than doubled, and the horse-power increased threefold.

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and, with a great hurrah, the other workmen seized the chains attached to the iron truck, and drew it to the incline by main force, where it was left by its own weight to run into the jaws of the rolling-mill. It was then *sauve qui peut* among the workmen, who rushed for shelter in all directions as the mass was nipped between the rollers, and wound rapidly in amid quick reports like those of dull musketry, as the melted iron was squeezed by the tremendous pressure out of the mass, and flew out in jets of liquid fire on all sides. In spite of all the care and all the skill which the best workmen can use on these occasions, they cannot always escape the splashes of melted iron, and the burns inflicted are numerous and often severe. The turning of the rollers crushes the plate through to the other side, where it rests for a minute on a wrought-iron truck similar to that on which it was brought from the furnace. The action of the rollers is then reversed after they have been by the action of screw levers brought closer together by about an inch. These again nip the plate and drag it back in an opposite direction, and again and again does the mass go forward and backwards, each time passing between a smaller space between the rollers, till, as on Friday, the whole of the huge thickness was reduced to a compact mass 15 inches thick, in less than a quarter of an hour. During every stage of the process, quantities of fine sand are thrown upon the plate, and this literally takes fire as it touches the flaming surface, and covers it as it melts with a coat of silica, or with a glaze like that of earthenware. After every discharge of sand, and these go on almost incessantly, buckets of water are thrown upon the plate and explode in clouds of scalding steam, and when these are partly dissipated men rush forward, and with wet besoms with handles 20 feet long sweep off whatever little scraps of oxidation may have taken place. Thus every time the plate passes through the mill the sand is scattered, the water thrown, and the surface swept, and at every roll the chief roller of the establishment runs forward, and, under the shelter of wet cloths, measures with a gauge its thickness from end to end. On Friday the required dimensions were obtained, as we have said, by less than a quarter of an hour's rolling, and a plate 15 inches thick, the product of the labor of nearly 200 men and of the consumption of nearly 250 tons of coal, was shot out by the rolling-mills and left to cool. When this had been effected two large rollers of iron, each weighing 15 tons, were placed upon it by the cranes, and moved slowly backwards and forwards, and, eventually, as the plate cooled, were left upon its ends to keep the whole perfectly level. Nothing further now remained in order to complete it as the finest specimen of armor-plate manufacture ever attempted but to plane off its rough ends and edges. The flat surfaces on either side, which form what is called the skin of the plate, are never interfered with, for the action of the steel rollers leaves them literally almost as smooth as plate glass."

Another industrial revolution, no less important than those already mentioned, has resulted from the invention of the steam-engine. With the advancement of mechanical art, precision in the execution of its processes becomes a requisite more and more indispensable. In the earlier period of the history of industry, and even until a time comparatively recent, no higher precision was obtainable than that of which the human hand is capable; and this could be secured only through the trained skill of the most accomplished artisans. Moreover, in proportion as the dimensions of the work to be executed were larger, or the weight of the mass to be operated on more considerable, the difficulties of the task were proportionally increased; so that a practical limit to accuracy was very soon reached. The state of the mechanic arts in this respect at the time of Watt's invention is well illustrated by the historical fact that, for more than ten years, owing to the impossibility of constructing a piston and cylinder steam-tight, the conception of the engine could not be realized in practice. This difficulty had nearly disheartened the inventor and ruined his associates, when, at length, Mr. Boulton, a capitalist, but, happily, also a metallurgist and engineer, entitled by his ingenuity, energy, and practical skill to be distinguished as the Whitworth of his day, came to his relief, and by means of the exceptional superiority of workmanship to which he had attained in his celebrated establishment at Soho, saved to the world the most valuable invention which had ever then been offered to its acceptance. And yet, though the invention was at last successful, it was but barely so. The earlier engines produced by Watt and Boulton would be regarded at this time as but little better than monsters of rudeness.

But the engine having succeeded, and having relieved the mechanical artisan of the drudgery attending his task, became presently an instrument of improving most remarkably the quality of his work. It was soon perceived that an iron arm could direct a tool with a precision which the most practised human skill could never attain. The class of mechanical contrivances called machine tools came into existence; and, in the manufacturing world at least, the file, the plane, the chisel, the auger, and the drill in the hand of man, except for the most trivial and unimportant purposes, entirely disappeared. With this change, also, there ceased to be a limit to the improvement of mechanical art, short of absolute perfection. Accuracy of workmanship has now reached a point at which the gradations of difference in dimension which it is perfectly in the power of the workman to give to an object on which he is employed, are entirely too minute to be perceptible, except by the aid of powerfully magnifying helps. A remarkable illustration of the fact here stated is furnished by Mr. Whitworth in a little contrivance for measuring, or rather for comparing, lengths, which is exposed by him in the annex in which his heavy guns are exhibited. This apparatus is designed to test the truth of a solid measure representing in length an English inch. It embraces, as exhibited, the standard inch with which the new one is to

be compared. This solid has the form of a rectangular prism, originally nearly or quite cubical. It is formed of polished steel. Its extreme edges have been truncated at angles of forty-five degrees, so as to reduce the terminal surfaces to the dimensions of about a quarter of an inch square. The lateral edges are also rounded, in order to facilitate the manipulation. It rests on a rectangular trough, of which the sides are equally inclined to the horizontal. At one of its extremities it abuts against a fixed stop, which is provided with the means of the necessary adjustment. The other is opposed to the extremity of a screw of twenty threads to the inch, placed directly in the line of the axis. A single revolution of the screw advances the extremity, therefore, one-twentieth of an inch. But the head of the screw is ten inches in circumference, and is divided into 200 parts. In turning this wheel, every division accordingly advances the screw one four-thousandth part of an inch. The divisions, however, are not traces, but teeth; and the screw-head is a gear-wheel, which is driven by a tangent screw lying horizontally in its plane and across its summit. And this tangent screw has also a head of 12½ inches in circumference, which is divided into 250 parts, each part being the twentieth of an inch. An entire revolution of the tangent screw advances the gear wheel only one tooth, which, as we have seen, moves forward the end of the measuring screw one four-thousandth of an inch. A single division of the limb of the tangent screw-head will therefore produce a movement in the direction of measurement of only one two-hundred-and-fiftieth of one four-thousandth of an inch—that is to say, of one one-millionth part of an inch; and to this degree of refinement it is Mr. Whitworth's belief that mechanical accuracy can be practically carried.

It might be said in objection, that while there is no fault to find with the correctness of the mathematical conclusion deduced from the known relations of the parts of this instrument, yet from the possible flexure or compression, or slight imperfection in the fitting of parts, there is room for error to the extent certainly of so minute a fraction as one one-millionth part of an inch; a fraction so minute that not only the senses fail to detect, but the mind is even incapable of conceiving it. Mr. Whitworth has anticipated this objection, and has met it by a practical and very ingenious answer. Between the plane face of the standard inch and the extremity of the measuring screw opposed to it, he has introduced a little steel plate with parallel and perfectly true surfaces, from the two opposite ends of which, for convenience of manipulation, there extend two slight arms in the direction of its plane. Before the measurement is begun the screw head is turned far backward, and this plate lies loosely between the screw and the standard, with its plane vertical, being sustained in this position by its arms, which rest on supports on each side. As the screw advances in the operation of measurement, the plate has less and less freedom of space, until at length it appears to be in actual contact with both screw and standard. But that this appearance is deceptive, is easily demonstrated by raising the plate slightly by means

of one of its handles, when, on being released, it will fall freely back, showing that it is not yet impeded by friction. If, now, the tangent screw be turned, a single division at a time, lifting the plate after each movement, a point will be reached at which, from perfect freedom, a single additional division of advance will fasten the plate completely, so that when lifted it will be held by friction at the point where it is placed, and will no longer fall. Between these two positions the screw has advanced one one-millionth of an inch; and the certainty that this is a real and not an ideal accuracy of measurement is proved by the fact that the operation may be repeated, and that, provided care be taken to guard against disturbance of the equilibrium of temperature, the arrest of the plate will continue to occur between the same two divisions of the screw-head.

Other illustrations of the exceeding mechanical accuracy which has been reached by the same ingenious exhibitor, may be found in the "true planes" and the gauges, of which an extended series has been presented by him in the Exposition. The gauges are perforated steel plates, the perforations being highly polished within, and differing from each other in diameter by one ten-thousandth of an inch. Corresponding to them are polished steel cylinders, one exactly fitted to each. As these cylinders lie side by side, it would be difficult for the eye to distinguish a difference of diameter between several of them; but when they are tried by the gauges, the difference is directly detected, since while each will pass freely through the aperture corresponding to its own number, no one can be forced without an effort into one of a higher order. The "true planes" are polished metallic surfaces of about one hundred square inches each. A pair of them are exhibited resting one on the other. They have a thickness of about half an inch, but are stiffened by means of deep ribs cast upon the reverse, which ribs connect the points, three in number, on which the plate is intended to rest when placed face upward. These plates nowhere deviate from true geometrical planes by an error exceeding the one one-millionth part of an inch. In the process of their construction they are ground one upon the other; but as by this means they might become truly adapted to each other without being necessarily truly plane, they are always constructed in triplets instead of pairs, the third plane serving to verify the other two. Indeed it is obvious that if, of two surfaces truly fitting each other, one should be convex and the other concave, a third could not possibly fit both. And only on the supposition that all three should be truly plane, could any two out of the three, chosen indifferently, fit equally well.

Of the two planes exhibited, when one is lifted and replaced upon the other, by a movement at right angles to its surface, it glides over the inferior plate more smoothly than if it were resting upon ice. This is because there is included between the two a cushion of air, which, however thin, serves to reduce, or as it might be said to annihilate, friction more effectually than could be done by any known lubricant. When, by

pressure and by sliding the plate to and fro, this cushion is pretty thoroughly expelled, the plates adhere so strongly that the upper will easily lift the lower by the effect of external atmospheric pressure, and would probably lift it though its weight were very much greater.

The extreme mechanical accuracy which the examples above described serve to illustrate, has been a consequence of the introduction into mechanical art of machine tools; and machine tools have owed chiefly their invention to the steam-engine. But it is not merely in respect to artistic excellence that the products of manufacturing industry have been improved by the improved methods of production; this improvement is attended also with a great economical advantage, resulting from the entire similarity of form and dimensions which distinguishes all the objects produced by the same process. When the hammer, the chisel, the file, the drill, in the hands of a man, were the only means of producing the various implements, machines, vehicles, and other constructions necessary for the daily uses of the farm, the family, or the workshop of the petty artisan, if a part became unserviceable it could not be immediately replaced, and possibly the whole machine became a loss. In modern manufacturing industry, no part of a construction is made for a particular machine, but what will serve for one will equally well serve for any other. A fracture of a wheel, or a lever, or a pinion, involves therefore but a momentary inconvenience. The loss is directly made good, and the machine moves once more.

But the steam-engine has not only increased the accuracy of constructive art; it has also greatly extended its power. Undertakings of a magnitude which could not have been attempted, and which would probably not have been thought of without it, have become by its aid operations of daily accomplishment, and are too familiar to attract especial notice. A mass of thirty or forty tons of metal is now wrought upon all its surfaces and transformed into any desired shape with greater facility and in vastly less time than would have been required at the beginning of this century to deal with half as many hundreds. This truth is illustrated in the immense ocean steamer crank-shaft exhibited by Mr. Krupp, wrought to its present difficult form, with elbows at right angles to each other, from a mass of twenty-seven tons, which in the operation has become reduced to fifteen; or the similar shaft exhibited by Messrs. Petin & Gaudet, of France; or the fifty-ton steel gun of the first-named exhibitor, and the twenty-five-ton gun from Woolwich; and the equally ponderous artillery shown by Mr. Whitworth, and by the government of France. To these illustrations may be added all the magnificent and splendidly finished forgings of the marine engines exhibited by the Creuzot works in their annex and on the Berge, to say nothing of the massive frames and bed-plates of the great machine tools themselves, the planing machines especially, exhibited by Whitworth of England, Sellers of the United States, Mazeline of France, and many others.

There remains to be mentioned one additional and most important

consequence of the invention of the steam-engine, which has impressed profoundly not merely the industrial but the political history of the world. If the cotton-gin has been for much in controlling the political and social destinies of the western continent, the steam-engine has been for still more in fixing for England her place among the nations of the earth. At the time when this splendid invention made its appearance, England called herself mistress of the seas, and assumed to be the equal, if not the superior, of any military power upon the land. This place she still claims, perhaps justly, though her title to the exclusive dominion of the waves can no longer pass unchallenged. But without the steam-engine, the power of England would have long since suffered a hopeless paralysis. It is from the depths of her mines that she has drawn the aliment which has sustained her manufactures and fed her boundless commerce and built up the enormous wealth which is the basis of her present strength. Her iron and her coal have made her a hundred times richer than she could possibly have been if she had possessed instead of them all the gold of California and all the diamonds of Brazil. But a century ago, just as Watt was turning over in his mind his first crude notions of the motor which was destined to transform the constructive industry of the world, many a thoughtful patriot and statesman of Great Britain must have been regarding with anxiety and alarm the stagnation which seemed to be gradually creeping over the mining industry of his country, and the danger which menaced with speedy total extinction this great source of her national wealth. As the mines were sunken deeper, the expense of lifting to the surface the mineral extracted, of course increased; but this was a trifling consideration compared with the vastly greater expense of withdrawing the water which flowed in, in constantly increasing abundance, and which had to be raised from a constantly increasing depth. In many instances mining had almost ceased to be remunerative; in many others quite. One after another the mines were abandoned and the water was allowed to fill them up. What had already happened in many instances could not fail to happen at length in all. An early ruin plainly impended over the mining industry of Great Britain, which could not fail to bring with it, and with the consequent failure of her fuel, an equal ruin to the manufactures, the commerce, the wealth and the political power of the British empire.

It was at this critical juncture that the new motor appeared. For some time after its appearance, it was only for the drainage of mines that its immense powers of usefulness seem to have been recognized. So imperfect at that time was the state of advancement of the mechanic arts! But applied to this purpose, then of paramount importance, it averted at once the imminent danger which menaced British industry, and restored to Britain the commercial sceptre just as it was about to fall from her grasp. The greatness of the British empire to-day is, therefore, clearly due to her early possession of the steam-engine. Without it she must inevitably and speedily have sunk to a level of comparative insignificance.

It is remarkable that, vast as was the revolution which the steam engine was destined to effect in the industrial world, the steps by which this was accomplished did not succeed each other with great rapidity. The first impression which the invention produced was in the relief it brought to mining. Its influence was next most distinctly felt in the development which it gave to textile manufactures. Then metallurgy yielded to its transforming power, and by degrees the same influence extended itself into every branch of mechanic art. But the applications of the new power to locomotion upon the water and upon the land, applications which were destined to infuse into commerce a life and activity which it had never known before, and so to react upon production indirectly no less effectually than the same cause had already done directly, came at long intervals, and required the greater portion of a century for their full realization. It is interesting to observe how, in the infancy of a great invention, conceptions which are perfectly just, struggle painfully and often for a long time abortively, to embody themselves into form. And it is sad as well as interesting to observe what chilling lack of sympathy usually attends their announcement, what obstinate prejudices rise up to oppose their introduction, what ridicule labors to dishearten their authors, and what contemptuous refusal of substantial aid operates to paralyze effort. The practicability of applying steam to river navigation was repeatedly demonstrated before the close of the 18th century; but it was only after a lapse of forty years from the invention of the engine, that Fulton, in presence of a great multitude, assembled chiefly in the hope of finding amusement in his discomfiture, made at length the decisive experiment which was to force this important truth upon the convictions of men beyond the possibility of further question. Twenty years more elapsed before it was clearly seen in what way the same power might be made subservient to the uses of locomotion on the land; and ten more still before the problem which had been so long completely solved for inland waters was admitted to be so likewise for the ocean. We stand at the end of the first quarter of a century since the Atlantic was bridged by steam; and within that brief period the entire naval and almost the entire commercial marine of the world has undergone a complete transformation. The tonnage of vessels has been doubled, the duration of voyages has been diminished more than half, and the interchange of wealth between nations has increased no less in quantity than in rapidity. The effect of all this upon productive industry everywhere is too vast to be computed.

We have instanced, thus, in the first place, an invention which has revolutionized a single branch of industry; and in the second, one which has produced a similar effect upon all industries. But the industries of the world are constantly growing in number, and an invention may sometimes possess a character so original as to be the means of creating a new one. An example of this kind may be found in the vulcanization of India-rubber; a process which has made of a substance which but a

few years since was limited to the narrowest range of uses, if rather it might not justly be called more curious than useful, the basis of one of the most important of existing manufactures. Photography furnishes another example of the same class; and this perhaps is a more happy selection, since the India-rubber manufacture can only be profitably conducted upon a scale of some magnitude, and is therefore concentrated in the hands of a comparatively small number; while photography adapts itself to all circumstances, and to the humblest resources, and may be practiced by an individual working alone in a garret, as well as by the operator on a grand scale whose saloons and laboratories occupy a palace, and whose assistants are numbered by hundreds.

It may be questioned, perhaps, whether, in the examples just cited, the processes at the foundation of the industries which they have created should not be called discoveries rather than inventions. This question is unimportant to the object for which the examples are produced, since, for the present purpose, it is immaterial whether a new industry is founded upon an invention or upon a discovery. Yet for the sake of precision of ideas it may not be amiss to mark the distinction. Discovery is the extension of the field of knowledge, the unveiling of a truth which though pre-existing was before concealed. Invention is the combination of known instrumentalities, truths, facts, or material things, in a way before unpracticed, to produce a definite end. Discovery therefore creates nothing. Invention creates. But knowledge, nevertheless, is the armory of invention, and every increase of knowledge increases the inventor's strength; so that the steady relation between the advance of discovery and the correspondingly growing efficiency of productive industry constitutes the most striking of all illustrations of the truth of the adage that "knowledge is power."

It follows from the distinction just drawn that a discovery may be accidental; but that an invention, since it implies design and forethought, cannot be so. The discovery of the polarization of light was accidental, but the invention of the saccharimeter, founded on this discovery, was the result of study.

A discovery, again, is sometimes made, which, while it can hardly be said to be purely accidental, is yet unexpected by the discoverer, who may be looking for something new, but not in the direction in which it presents itself. An example of this kind is furnished by the discovery of indium, brought to light in the study of the solar spectrum. Such discoveries may be called incidental. The early history of chemistry is full of them, and among the most important of the number may be ranked the mineral acids, evolved from their combinations by the alchymists of the middle ages in the course of their empirical pursuit of visionary objects. It is curious to observe how powerful has been the influence upon the history of productive industry of discoveries like these, coming unlooked for and unappreciated when made, but possessing, nevertheless, a potential value, in comparison with which the philosopher's stone itself,

the great object of the researches which made them known, would have been worthless.

But although a discovery may often thus be made without effort or without intention on the part of the discoverer, it has occasionally a larger part in the foundation of an industry than any supplementary invention which may be necessary to draw from it a practically useful result. Such is not, however, the rule. More usually invention and discovery go hand in hand, and lend each other mutual aid. Discovery is constantly the basis of invention. The very first thought which presents itself on the acquisition to our pre-existing stock of knowledge of any new truth in chemical or physical science, is, what shall we do with it for the benefit of the human race? It is not always that we see for the moment what we shall do with it. The truths the most ultimately prolific have often continued to be for a time after their first announcement comparatively sterile. But the history of the past has shown that no truth is ultimately useless, while most new truths act almost instantaneously to stimulate invention.

In the case of a few of the great inventions by which the world has been benefited, the effect has been to act more immediately and more powerfully upon the moral and intellectual character than upon the material condition of the human race. Pre-eminent above all others in this class must be ranked the capital invention of printing; an invention which, by opening the way to universal education, has wrested the priceless treasures of knowledge from the possession of a favored few, and given them to be the common property of all mankind. Nor is the value of this grand invention fully told, when we say that it has substituted knowledge for ignorance. Ignorance implies something more deplorable than merely not to know; it implies superstition, credulity, cruelty, degraded tastes, mean and grovelling ambitions. An ignorant people is almost of necessity an enslaved people. Without capacity for combination, without expansiveness of views, unacquainted even with its own strength, and in slavery already to phantoms of the imagination, such a people succumbs easily beneath the yoke which a bold will and an iron hand impose. An ignorant people is also a people to a greater or less degree brutalized; a people whose better nature is obscured, whose larger capabilities are undeveloped, and whose most salient characteristics are too generally only low cunning, petty selfishness, and an obtuse moral sense. Deliverance from ignorance is emancipation from bondage, the awakening of the nobler faculties of the better sentiments and of the more generous susceptibilities of humanity, and the elevation of man to the position of dignity among created things which he has been capacitated by his Maker to occupy. Without the printing press such deliverance was no doubt possible, but it was possible only to the few; for the multitude, servitude, mental darkness, moral debasement, physical suffering, remained the inevitable destiny. Of such an invention the value can be measured by no ordinary or sordid standard. The industrial advantages which have

followed in its train are unworthy for an instant to be compared with the results of that beneficent influence which it has exercised over the minds and the hearts of men.

A similar character, though not so distinctly marked, must be ascribed to the invention of the electric telegraph. The rapid diffusion of intelligence which this splendid triumph of human ingenuity has made possible between points most widely separated from each other upon the earth's surface, has contributed, and is contributing, much, though to common observation it may be insensibly, through the increase of knowledge which it brings, and through the lively stimulus it is affording to intellectual activity, to promote the growth of popular enlightenment throughout the world. It is probable that this invention is about to prove one of the most powerful instrumentalities ever known in breaking down the barriers between nations, in gaining acceptance for the doctrine of the solidarity of peoples, and in advancing the march of civilization over lands on which the shadow of barbarism is still resting. The telegraph is invading central Asia, and is menacing the heart of the Chinese empire. With such an agency constantly at work, another century cannot fail to effect, among the secluded peoples of those remote regions, changes, social, industrial, and possibly political, more signal and more singular than any that have taken place among them hitherto since the age of Confucius.

There may seem to be something paradoxical in ascribing, as to some extent may certainly be justly done, a similar influence to an invention of earlier date, of which the immediate result was rather to arm men more effectually for each other's destruction than to draw them together into a common bond of brotherhood—the invention of gunpowder in the 14th century. Yet it cannot be denied that whatever tends to diminish the frequency of wars, or to lessen their horrors when they occur, is so far at least promotive of the spirit of peace. The strifes which take place between modern nations are no longer prosecuted with the sanguinary ferocity which marked the military conflicts of earlier times; battles are no longer fierce personal struggles in which each man meets his adversary hand to hand; victory is no longer the signal for indiscriminate massacre, and the horrible war-cry *væ victis* has ceased to be the shout of the conquerors. The improvement may in some degree be due to the transforming power of Christianity in the later centuries, and to the softening of men's spirits under the genial influence of an advancing civilization. Yet it has often been also attributed, and in measure at least with apparent justice, to an invention which, though it has rendered weapons more deadly, has made it henceforth unnecessary that the conflicts of men should resemble the fights of tigers, and has made science an element of the art of war no less important than physical force.

In classifying inventions as they affect the industrial world, we may, then, distinguish them in the first instance into two groups, according as they seem to be of primary or of secondary importance. In the former

of these groups may be placed, first, inventions whose effect is to transform an industry already existing, and to give to it an increased relative importance; next, those which are the means of originating new industries; then those whose influence is not special, but is felt throughout the whole industrial field; and finally, such as, in addition to their value as contributions to productive power in the material world, act directly as instrumentalities in promoting the mental and moral advancement of the human race.

Among inventions of the second order of importance will be classed, of course, such as are avowed modifications or improvements, often very real, of those of the first; remedying the imperfections of an original process or machine, and contributing to a more satisfactory result; then, such as, without creating a new industry or transforming essentially an existing one, facilitate or tend to expedite certain of the operations incidental to a manufacture; then, such as add to the minor comforts, conveniences, and enjoyments of life; and finally, such as, in place of the multitude of common objects and implements in daily use among men of all trades and professions, substitute others of improved form, or better material, or more moderate price.

This classification may not be exhaustive, but of its propriety, so far as it goes, the Exposition furnished a large variety of illustrations. To illustrate the distinction by example, the original sewing machine may justly claim a place in the first group; but its various modifications, its adaptations to embroidery, to harness-making, to the working of button holes, &c., must be referred to the second. The varieties of mechanism employed in the formation of the stitch in common sewing must all take the same direction. Some of these have evidently been devised not so much in the hope of a real improvement as for the sake of securing a patentable form of a popular machine. Among the number, however, it is but justice to distinguish one which possesses a very distinctive merit. The machines which employ but a single thread have the advantage of superiority in point of simplicity of construction and of facility of management; but they have the great disadvantage generally of producing a seam which, when it fails at a single point, fails everywhere. To make a seam with a single thread which will not yield when cut across is a very signal improvement; and this result seems to have been effectually achieved in the machine of Wilcox & Gibbs, of New York. By an unfortunate mistake this machine did not come under the observation of the jury of the class to which it belonged, and it failed, therefore, to receive the recompense which was justly its due. Another illustration of this class of secondary inventions presented itself in the Jacquard looms, exhibited by Mr. Pinel de Grandchamp, of Paris. In the weaving of complicated patterns with these machines, the multiplicity of perforated cards which are necessary to govern the movements of the warp becomes an inconvenient incumbrance. The inventor has successfully disembarrassed himself of this incumbrance by the simple expedient of substi-

tuting for the cards a continuous sheet of perforated paper. By this substitution there was secured at once the double advantage of superior convenience and diminished expense. Still another and very interesting illustration of similar character was seen in the power looms and knitting machines exposed by M. M. Radiguet and Lacène in the same class. This consisted of an ingenious attachment designed instantly to arrest the movement, if at any time the spool became exhausted in the shuttle, or the yarn happened to break. A delicate metallic finger was seen to feel for the yarn at the very instant the shuttle completed its course. If the yarn was in its place it rested there, and the work went on; if not, it made an electric contact, and the power was paralyzed in an instant. In pattern work the advantage of such an attachment will easily be understood. No time is lost in studying to find where the pattern began to be interrupted, and no trouble is necessary to set backward the Jacquard guides.

As an example of what is intended in the second subdivision of inventions of this order, may be mentioned Armstrong's machine for dovetailing, exhibited in the American section. The rapidity and accuracy with which this ingenious contrivance executes one of the most troublesome details of joinery, which it has hitherto been necessary to accomplish slowly by hand, was a subject of constant interest to crowds of admiring spectators. Most machine tools of which the purpose is special, and many of the inventions auxiliary to rural industry, may be referred to this subdivision.

To the third subdivision belong whatever relates to furniture and dwellings, to modes of heating, illumination, and ventilation, to food and culinary operations, to wearing apparel, conveyances, cutlery, &c., &c.; and to the fourth, the various implements and tools used in the hand by men of all trades and professions. And in addition to these things there are, doubtless, many miscellaneous inventions which this classification is not sufficiently complete to embrace.

If, in view of the distinctions which have been thus drawn between the different classes of inventions, we turn our attention to the novelties presented in the Exposition of 1867, we shall be led to infer—

1. That the number of inventions entitled to be called new in the sense that they are here first made known or first publicly exhibited is not remarkable. It is natural that this should be so, since it is the interest of every inventor, so soon as he has perfected his title, to publish his invention as promptly and as extensively as possible, while until that time it is equally his interest to keep the knowledge exclusively to himself. So abundant, also, and so rapid are the means of intercommunication at present existing between civilized nations, and so numerous are the channels of intelligence which the press has provided for every industrial speciality, that no invention, no improvement, no important change of any description can take place anywhere without becoming almost immediately known, in character at least if not in detail, throughout the

world. On the other hand, the number of inventions here presented, which are new in the sense that they are *recent*, is very large; and if all which are of secondary, as well as those of primary, importance, or all which are only improvements on pre-existing inventions, are to be included, it is a great deal too large to be easily enumerated.

2. The number of recent inventions illustrated in the Exposition which have effected, or are effecting, large changes, and even revolutions, in important departments of the world's industry, is very considerable; and among these there are some which are destined to stimulate production, in the departments to which they belong, to an extent which we can as yet but imperfectly estimate. It is in the nature of such influences to work out their results by degrees; and the magnitude of their importance is only perceived in proportion as these results become apparent. Very conspicuous in this class must be ranked the improved processes which, in later years, have been introduced into the manufacture of steel; and yet, largely as these have already modified the metallurgy of the age, the benefits which must result from them to the industrial arts generally, and especially to mechanical, civil and military engineering, are only beginning to be felt. Galvanoplasty is another great invention of recent times; but it is one of which the capabilities have been developed more gradually still. For a long time it was believed to admit of no more important useful application than to the reproduction of works of art; but it is employed at present for the preservation of important structures of iron in situations of exposure, where they are liable to be rapidly destroyed by corrosion; it is an invaluable auxiliary to the art of heliographic engraving; it gives durability to the printer's type; and, in one way or other, it contributes something to the perfection of almost every useful art. A few years since the numerous public fountains of Paris—huge structures of cast-iron—were rapidly becoming unsightly objects from the rust which accumulated upon their surfaces. They have been coated by the galvanoplastic process with a shield of copper, which completely protects them against further injury, and have, consequently, now all the beauty of bronze combined with the cheapness of iron. Thus inventions of the first order of importance are not seldom slow to be recognized as such; and in regard to such an invention, the term recent must be applied with a larger latitude of meaning than is understood when we speak of one which produces its impression immediately. Of this latter description was the invention of the reaper, which took the world almost by storm; and the same remark is true of the planing machine, the sewing machine, and other signal industrial innovations of analogous character. A machine, in fact, which performs a definite work makes its way much more rapidly than a process, or even a mechanical contrivance, of which the possibilities of application extend to many varieties of work. One of the former description may, therefore, soon cease to be new, while one of the latter will be always new so long as the development of its capabilities continues to be progressive.

It results that whoever should attempt, in a great industrial display like the Exposition of 1867, to take note of every interesting invention of recent origin which the exhibition embraces, would attempt an impracticable task; and that whoever should propose to select from among the number such recent ones as are of most prominent importance, would be obliged to understand the word recent as covering a period of some years. Such a selection it is which has been attempted in the notices which follow; and in making the selection it has been a purpose kept in view to avoid, as far as possible, encroaching upon ground which, in the distribution of duty, had been assigned to others. This explanation may account for the omission of any mention in this report of many objects whose comparative importance would entitle them to occupy a conspicuous place in any comprehensive record which should be made of the memorable things embraced in this Exposition.

CHAPTER II.

MOTORS.

HOT-AIR ENGINES—ADVANTAGES AND DISADVANTAGES—CLASSIFICATION—THEORETIC LIMIT OF ECONOMY—ERICSSON'S HOT-AIR ENGINE—SHAW'S—BELOU'S—ROPER'S—LAUBERAU'S — WILCOX'S — FRANCHOT'S — INFLAMMABLE GAS-ENGINES—OTTO AND LANGEN'S—LENOIR'S—HUGON'S—AMMONIACAL GAS-ENGINES—FROT'S—DELAPORTE'S —ROTARY STEAM-ENGINES—BEHREN'S—PILLNER AND HILL'S—SCHEUTZ'S—THOMPSON'S—ROOT'S SQUARE PISTON ENGINE — HYDRAULIC MOTORS —WATER-WHEELS—TURBINE WHEELS—WATER-PRESSURE ENGINES—GIRARD'S HYDRAULIC PIVOT—AERIAL MOTORS—ELECTRO-MAGNETIC ENGINES—CAZAL'S — BIRMINGHAM COMPANY'S —KRAVOGL'S.

GENERAL OBSERVATIONS.

Force being the first necessity in all industries, it is natural that the agencies designed to furnish motive power should receive the first attention. The steam-engine, in its several forms fixed and movable, with the exception of the rotary engines, having been made the subject of examination and report by another committee, will require no notice here. It is sufficient to remark in this place that, notwithstanding the inappreciable usefulness of this machine, and notwithstanding the many and very great improvements which have been introduced into it since the time of Watt, the steam-engine is still not without some features which, if it were possible, it would be desirable to avoid. Though it has been reduced to a form comparatively compact, it still occupies an amount of space which is for many purposes inconvenient; and though for a given power the cost of construction is less at present than it was a quarter of a century ago by more than fifty per cent., it is still costly. The improvements of boilers have very largely increased the amount of heat utilized, and have so reduced the bulk and weight necessary to the production of a given power as to have made the introduction of the movable engine into agriculture and into many of the minor industries economical, and not too inconvenient. Yet, for intermittent industries, the time consumed in raising steam to the required pressure, and the unproductive expenditure of fuel which is the consequence of the frequent repetition of this operation, are sensible disadvantages; and to these must be added the disastrous effects which usually accompany the accident of an explosion of the boiler; an accident which, however rare, is always possible, and against which no caution or foresight can provide an absolute security. Much ingenuity has therefore been enlisted in the endeavor to provide a motor which, in certain circumstances, if not in all, might replace the steam-engine. If, as yet, the success of these efforts has not equalled the hopes of their authors, it has still been

considerable, and it has probably by no means yet reached its culminating point. The "motors" of this description which presented themselves in the Exposition may be arranged under several heads, as follows:

1. Hot-air engines; 2. Inflammable gas-engines; 3. Ammoniacal gas-engines; 4. Rotary steam-engines; 5. Hydraulic motors; 6. Aerial motors; 7. Electro-magnetic engines.

I.—HOT-AIR ENGINES.

Of engines driven by heated air, several varieties were exhibited. All of these have certain advantages in common, and all are subject to certain disadvantages which are inseparable from the system. It is an advantage that they require no boiler, and are exempt from the dangers which arise from that source. Could air be employed at a pressure equal to that of steam, it would be an important advantage to be free from the great weight which the use of the boiler necessitates, and unembarrassed by its bulk. As yet, however, this condition has not been realized, and hence the dimensions of the working parts of air-engines are necessarily so much more considerable than those of steam-engines of corresponding power, as to render the gain in this direction, if there is any, unimportant. It is, however, an advantage that air-engines are cheaper of construction than those driven by steam, and that their management is easier, and requires less constant watchfulness. It has generally been claimed for them that they economize fuel. Theory might seem to justify this claim, but in practice it has hardly been sustained.

The disadvantages of air-engines consist in the difficulty of heating and cooling the air employed with the rapidity necessary to secure the best performance; and in the fact that the supply of the cylinder consumes more than half the power developed. To this it may be added, that, while the efficiency of the machine depends upon the difference between the maximum and minimum temperatures, there are certain practical limits which neither of these temperatures can transcend.

Air-engines may be arranged in two classes, of which the first embraces those which draw their supplies directly from the atmosphere, and discharge them into the atmosphere again after they have produced their effect; and the second, those which employ continually the same air, which is alternately heated and cooled but is not allowed to escape. The Ericsson engine which has been established among us for many years, and which, for minor industries, is in so great esteem, is an example of the first class. The engine of Mr. Lauberau, which will presently be described, illustrates the second.

In each of these classes a subordinate classification may be made according as the air is heated in the cylinder in which it performs its work, or in a separate chamber. The plan of the Ericsson engine is the first of these. That of Mr. Shaw's invention exhibited in the Ameri-

can section, and also of Mr. Roper's in the same section, the second. Of machines which do not discharge the air, Mr. Lauberau's was the only one exhibited. In this, the work is done in one cylinder, and the heat is applied in another. This class of machines admits of several modifications of arrangement, all of which have been employed by different inventors with more or less success. The heater and the refrigerator, for example, may be both independent of the working cylinder, and of each other; presenting an analogy to the boiler and condenser of the steam-engine; or the refrigerator only may be separate; or finally, as in the engine of Mr. Lauberau, the heating and refrigeration may take place at the opposite extremities of the same vessel, the air being driven from one end to the other alternately by means of a plunger.

Certain propositions are true of all these machines. In the first place, there is a theoretic limit to the economy of which they are capable—that is to say, of the heat which the air receives from the source, a fraction only can under any circumstance be converted into mechanical force; and theory enables us to state the maximum value which this fraction can have. This maximum depends only on the extreme temperatures at the command of the engineer; and is therefore the same for all hot-air engines, and not only for these but for all engines whatever driven by heat, whether the elastic medium employed be air or steam, or ammonical gas, or the vapor of ether or of any other volatile liquid. But in no engine yet constructed has this economical limit been reached, or even very nearly approached.

As the proposition here stated is a very important one, it is proper to devote a few words to its illustration. Its truth is directly demonstrable from the principles of the mechanical theory of heat. In fact, when the elastic force of air or steam is employed as a motive power, the maximum limit of possible advantage, and therefore of economy, is easily ascertained, by following the successive changes, in regard to volume and temperature, through which a limited portion of the elastic medium (a single charge, for instance, of the working cylinder) must pass, in order that it may produce the largest elementary portion of work of which it is capable, and be restored to its original condition, or to the state in which it may be available to produce a second useful effect. In practice this cycle is not usually completed; and the same portion of the elastic medium is not made repeatedly serviceable. At a certain point of its expansion, the steam or the heated air is discharged into the atmosphere, while a fresh portion is taken up to supply the place of that which is thus abandoned. When, in the case of steam, a condenser is used, the water produced by condensation is returned to the boiler; but here the regularity of the cycle is broken by the abrupt condensation of the steam before it has performed all the work of which it is capable. On this account no steam-engine fulfils the conditions of largest economy. But the fraction of work which is voluntarily sacrificed could usually be saved only at the expense of a more than compensating incon-

venience. In the case of steam, the cycle of changes which takes place in the production of the largest possible amount of available force of which a given volume of the medium is capable, consistently with the supposition that it is finally restored to its original state, so as to permit a repetition of the effect, is the following:

First. The large expansion attendant on the conversion of water into steam with the volume due to the temperature and pressure of the boiler.

Secondly. The dilatation of this steam with diminishing pressure and temperature, until its elastic force is in equilibrium with that of the surrounding media—of the atmosphere, in the case of a non-condensing engine, and of the vapor in the condenser, in a condensing engine.

Thirdly. The reduction of the volume of this steam, or mixed steam and water, without elevation of temperature, (that is, with a constant abstraction of the heat produced by the compression,) to such a bulk that,

Fourthly, a final compression, *without* abstraction of heat, shall restore it to the boiler in the form of water under the original temperature and pressure. In the third step of this progress the force required for the compression is constant, and is simply that which is necessary to clear the cylinder against the resistance of the atmosphere or of the vapor in the condenser; but it is attended with progressive condensation of the vapor still remaining to the form of water; the latent heat thus developed being supposed to be removed by suitable means of refrigeration. In the final compression it is the force of increasing pressure which completes the condensation; and the developed latent heat brings up the temperature of the water to that of the boiler. In this series of changes, the expansion in the first term and the compression in the third are attended with no change of elastic force, since the temperatures remain constant, and the densities also; vaporization, on the one hand, and condensation on the other, compensating for change of volume. In the first stage heat is constantly received from the fire; and in the third it is constantly abandoned to the refrigerator. In the second and fourth no heat is either received or given up. There is constant loss in every stage by the effect of radiation and conduction; but this, in the abstract theory, is not considered, and in practice is guarded against as far as possible. When the medium employed is air, or a permanent gas, the cycle of changes is similar, but the pressures are variable throughout. In the first and third stages the temperatures are constant, as in the case of steam. In the second the temperature falls, and in the fourth it rises. During the first stage heat is received from the fire in such quantities as to prevent any depression of temperature in consequence of the expansion, but not enough to produce any elevation of temperature. This heat is entirely converted into work, and is the exact equivalent of the work done in this part of the cycle. During the second no heat is received or given up: but the temperature falls, and the work done is the equivalent of the heat which thus seems to disappear. In the third the volume is reduced by compression, and a refrigerator absorbs the heat which the compres-

sion developes, so as to maintain a constant temperature; and in the fourth further compression elevates the temperature to that with which the cycle commenced, while at the same time it restores the original bulk. In this change the temperature rises through as many degrees as it fell during the second period; and the same amount of heat which then seemed to disappear now makes its re-appearance. The work done with positive effect in one of these two stages balances that which is expended unprofitably in the other; so that the amount which is finally available for *use* is the difference between the work which is performed during the expansion in the first stage and that which is consumed in the compression which takes place in the third. And this, as we have seen, is measured by the heat received from the fire, diminished by the heat imparted to the refrigerator.

The foregoing propositions may be visibly illustrated by means of a simple geometrical figure. If we suppose a body of air, or other elastic medium, to be confined in a cylinder between the closed extremity and a movable piston, the distance between this extremity and the piston will be always proportional to the volume. In the annexed figure let O

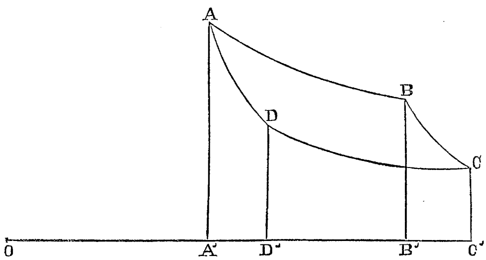

Fig. 1.

be the closed extremity of the supposed cylinder, and A′, B′, C′, D′, positions occupied by the movable piston at the end of the successive stages of expansion and compression which we have supposed the air to undergo. Then let AA′, BB′, CC′, DD′ be perpendiculars proportional to the pressure exerted by the air upon the piston at those several points. The first stage of expansion is represented by the movement of the piston from A′ to B′, during which the temperature is constant, and the pressure falls off gradually. The work which is done during this period is proportional to the area ABB′A′. The second stage of expansion corresponds to the movement of the piston from B′ to C′. During this period no heat is supplied by the source, and the temperature falls. The pressure also diminishes more rapidly than before, and the work done is proportional to the area BCC′B′. The first stage of compression occurs while the piston moves from C′ to D′, in the direction opposite to that of its former movement; and as, during this period, the refrigerator removes the heat generated by compression, the temperature remains constantly the same, and the work consumed in overcoming the resistance of the air is proportional to the area CC′D′D. Finally, in the move-

ment of the piston from D′ to A′, its original position, the refrigerator no longer acts, and the temperature rises, the pressure rising at the same time more rapidly than before. D′ may be taken at such a point that the final pressure shall be equal to the initial pressure AA′. In this last movement, therefore, the work consumed will be proportional to the area DD′A′A.

Thus we have, for the positive effect of expansion, the entire area ABCC′A′. But, in order to restore the air to its original state, there must be expended a force represented by the area ADCC′A′. And it is only the difference between these two values, or the force which has the irregular area ABCD for its representative, which is available for useful effect.

It is provable that the area BCC′B, described under these circumstances, is equal to the area ADD′A′. Hence, in fact, the area representing the available force ABCD is equal to the difference of the areas ABB′A′ and DCC′D′. The first of these areas is that which is described with the superior temperature constantly continued; and the second that which is described with the inferior temperature similarly constant. The other two effects, being equal and opposite, may be disregarded.

Now the heat consumed in expanding an elastic fluid through a space bearing a definite proportion to its bulk without change of temperature, (which is the measure of the work done at the same time,) must of course be proportional to the pressure; and this is itself proportional to the temperature measured from the absolute zero, two hundred and seventy-three degrees below the zero of the Centigrade thermometer. And the heat developed in compressing a similar fluid through a similar space must, for the same reason, be proportionate also to its temperature. The actual bulk of the air during the expansion in the first stage of the cycle above described, and during the compression in the third stage, is not the same; but the ratios of the bulks at the beginning and end of the expansion, and at the beginning and end of the compression, are equal, and accordingly the quantities of heat received in the first instance from the fire, and imparted in the second to the refrigerator, are proportioned to the temperatures at which the expansion and compression take place. It hence appears that, of the heat required to operate an air-engine which fulfils the conditions above described, the proportion which is convertible into useful work will be greater or less, according as the maximum and minimum temperature differ more widely. And what may be called the coefficient of economy for such an engine may be thus expressed:

If T be taken to represent the superior temperature measured from the absolute zero, and T′ the inferior; and also Q to represent the quantity of heat received from the fire during the first expansion, and Q′ the quantity transferred to the refrigerator during the first compression; and finally, if A represent a constant quantity dependent on the absolute pressure and bulk of the gas at a given temperature, then we shall have, $Q=AT$; $Q'=AT'$; $Q-Q'=A(T-T')$.

As Q—Q′ is the portion of the heat utilized, and Q the entire amount received from the fire, the economical coefficient, or the fraction showing the ratio to the whole of the part which is made usefully available, and which may be represented by U, will be,[1]

$$U=\frac{Q-Q'}{Q}=\frac{A(T-T')}{AT}=\frac{T-T'}{T}$$

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[1] If the effects of the several movements described in the text are expressed analytically, the truth of the propositions above stated will be evident from a mere inspection of the formulæ.

Let it be premised that whenever a determinate mass of air, or other perfectly elastic medium, changes its volume without changing its temperature, the pressure will be inversely proportional to the volume. That is, if p_a and v_a denote a given pressure with its corresponding volume, and p_n and v_n any other pressure and volume coexisting, then

$$p_a : p_n :: v_n : v_a; \text{ or } p_n v_n = p_a v_a. \qquad \text{(I.)}$$

Also, if while volume varies the temperature varies, but pressure remains constant, then, putting t_a and t_n for the given and variable temperatures, respectively, as measured from the absolute zero, the temperature must vary as the volume, or

$$t_a : t_n :: v_a : v_n; \text{ or } t_n v_a = t_a v_n.$$

And, if the pressure varies while the volume remains constant,

$$t_a : t_n :: p_a : p_n; \text{ or } t_n p_a = t_a p_n.$$

Accordingly, if temperature, pressure, and volume all vary together

$$t_a : t_n :: p_a v_a : p_n v_n; \text{ or } t_n p_a v_a = t_a p_n v_n. \qquad \text{(II.)}$$

Finally, if the same determinate mass varies in volume without receiving or parting with heat,

$$t_a : t_n :: v_n^{\gamma-1} : v_a^{\gamma-1}; \text{ or } \frac{t_n}{t_a}=\frac{v_a^{\gamma-1}}{v_n^{\gamma-1}}; \text{ and } \frac{t_a-t_n}{t_a}=\frac{v_n^{\gamma-1}-v_a^{\gamma-1}}{v_n^{\gamma-1}}. \qquad \text{(III.)}$$

Also

$$\frac{v_n}{v_a}=\left(\frac{t_a}{t_n}\right)^{\frac{1}{\gamma-1}}. \qquad \text{(IV.)}$$

In which γ is the thermo-dynamic index of the medium, or the ratio of the specific heat at constant pressure to the specific heat at constant volume. In the case of air, $\gamma=1.421$.

Now if p_1, p_2, p_3, and p_4 denote the pressures at the commencement of the successive movements described in the text, severally; and v_1, v_2, v_3, and v_4 the corresponding volumes at the same time; and if t_a and t_b be the two extreme temperatures, and W_1, W_2, W_3, and W_4 represent the amount of force expended or work done in these movements, respectively, then the total useful effect resulting from the whole series, W_u, will be expressed in the equation,

$$W_u=W_1+W_2-W_3-W_4.$$

Of these the values of the second and fourth are—

$$W_2=\frac{p_2 v_2}{\gamma-1}\left(\frac{v_3^{\gamma-1}-v_2^{\gamma-1}}{v_3^{\gamma-1}}\right), \text{ and } W_4=\frac{p_1 v_1}{\gamma-1}\left(\frac{v_4^{\gamma-1}-v_1^{\gamma-1}}{v_4^{\gamma-1}}\right).$$

Here $p_2 v_2 = p_1 v_1$, because the temperature from v_1 to v_2 is constant and equal to t_a, (I.)

Also, (III), $$\frac{v_3^{\gamma-1}-v_2^{\gamma-1}}{v_3^{\gamma-1}}=\frac{t_a-t_b}{t_a}=\frac{v_4^{\gamma-1}-v_1^{\gamma-1}}{v_4^{\gamma-1}}.$$

Hence $W_2=W_4$, and the equation is reduced to,

$$W_u=W_1-W_3.$$

The values of these two terms are—

$$W_1=p_1 v_1\left(\text{h. l.}\frac{v_2}{v_1}\right), \text{ and } W_3=p_4 v_4\left(\text{h. l.}\frac{v_3}{v_4}\right).$$

But, (IV), $$\frac{v_4}{v_1}=\left(\frac{t_a}{t_b}\right)^{\frac{1}{\gamma-1}}=\frac{v_3}{v_2}. \quad \text{Consequently } \frac{v_2}{v_1}=\frac{v_3}{v_4}.$$

It follows that, in proportion as the interval between T and T′ is increased, the machine will work with correspondingly greater economy. This interval can be increased by increasing T, or by diminishing T′, or by doing both at once. It is impracticable, however, to employ a refrigerator having a temperature below that of the weather. We must therefore take for a mean lower limit about 17° C, or 62° 5 F, a temperature which, referred to the absolute zero, is equal to 290° C. On the other hand, a practical upper limit is imposed by the consideration that a red heat is reached for solids at about 650° C, which is 923° C above the absolute zero. This limit could not be safely approached; but supposing it to be actually attained, the economical co-efficient would be

$$\frac{923-290}{923}=0.684$$

or a little more than two-thirds of the heat taken up by the air. Probably no hot-air engine has yet been actually employed, in which the temperature has been carried much above 300° C. With a maximum temperature of 307° C = 580° C above the absolute zero, the economical coefficient would be

$$\frac{580-290}{580}=0.50$$

which would show a utilization of one-half the heat taken up. The first Ericsson engine was designed to work at a maximum temperature of about 450° F = 232° C = 505° above the absolute zero. The limit of economy realizable by it, had it been successful, and provided the air could have been made to pass through the complete cycle of changes embraced in the theory, would have been

$$\frac{505-290}{505}=0.426.$$

But in point of fact, no hot-air engine fulfils, or can fulfil completely, the theoretic conditions. In order to do so, it would be necessary that the air should leave the working cylinder at the minimum temperature; that is to say, at a temperature as low as that of the supply; or else that, by some contrivance, the excess of heat which it retains should be transferred to the supply on its way to the working cylinder. As the first of these conditions—that is to say, the expansion of the air in working sufficiently to reduce the temperature to the minimum—is practically unrealizable, it is the second which inventors have in many instances

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Also, (II), $t_b\, p_1\, v_1 = t_a\, p_4\, v_4$; and $p_4\, v_4 = \frac{t_b}{t_a}\, p_1\, v_1$

Hence $W_u = W_1 - \frac{t_b}{t_a} W_1 = W_1 \left(\frac{t_a - t_b}{t_a}\right)$; and $\frac{W_u}{W_1} = \frac{t_a - t_b}{t_a}$

Thus, as W_1 is the mechanical equivalent of all the heat that has been imparted to the medium, the fraction expressing the greatest possible useful effect, or the *economical coefficient*, is formed by taking the difference of the extreme temperatures for a numerator, and the maximum temperature for a denominator.

sought to secure. In order to accomplish this, the emergent air has in some cases, as in Ericsson's original engine, been made to pass through successive sheets of wire gauze, or between thin sheets of metal, or has been in some other manner brought into contact with metallic surfaces of large extent in proportion to the weight of the mass, in order that the excess of heat being transferred to these might be afterwards taken up by the cold air of the supply as it enters. The first of the expedients here mentioned was employed by Mr. Ericsson, and the second in the earlier invention of Sterling. In Shaw's engine, exhibited in the Exposition, the hot air escapes through a cluster of thin tubes, while the cold air circulates between them. The term "regenerator" was applied by Mr. Ericsson to this contrivance as applied to his original engine, and this term has come into general use. The regenerator is applicable to any form of engine, but it is not employed in all. The theoretic advantage is considerable, but in practice is not fully realized; and it is attended with the disadvantage of sensibly increasing the amount of the passive resistances of the machine. In fact, in order that the regenerator, suppose it for instance to be a succession of wire gauze sheets, should entirely absorb the excess of heat of the escaping air, the number of sheets should be very considerable. It is easily seen that if this number were quite unlimited, there would be somewhere a point at which the air would have no longer any heat to impart; its temperature being sensibly reduced to that of the metal. From this point backward to the cylinder from which it was discharged, the successive sheets of wire gauze would rise in temperature, and the last one would have sensibly the same temperature as that with which the air emerged. The number of sheets which would be required effectually to absorb the heat, would depend, for a given excess of temperature, upon the closeness of the meshes, and in any case must be considerable. The obstruction which every such contrivance necessarily presents to the free passage of the air, creates a resistance which makes its presence objectionable, and which may go far to neutralize the advantage which it is designed to secure. By diminishing the number of the sheets and the closeness of the meshes, the resistance is reduced, but the absorption of the heat is proportionally less complete. Practically, where the regenerator continues to be used, a middle course is taken; the economy is not wholly realized, and the obstruction to circulation is not very serious. This is the case in the engine of Mr. Shaw, in which the regenerator consists, as above remarked, of a series of tubes. It is to be considered, however, that the loss of heat suffered in operating engines driven by heated air or steam, is by no means limited to the fraction, large as it is, of the heat which, after being actually imparted to the medium, is unavailable for work. If this were true, the cost of working such engines would fall to a very small proportion of what it actually is. It is, unfortunately, the case that by far the largest source of loss is to be found in the escape of a large part of the heat which the combustible develops in other ways than in raising the temperature of

the elastic medium which does the work. And the improvement of all these engines, so far as economy is concerned, is to be sought in such forms of furnace, and such modes of applying heat, as may reduce what is now the sheer waste of the chimneys or of the radiating surfaces, rather than in the endeavor to push to extremes the temperatures employed in the working cylinder.

It is to be observed that the difficulty of guarding against losses by conduction and radiation is enormously increased when excessive temperatures are employed; and also that such temperatures decompose lubricants, destroy packing, and, by the large expansion which they give to metals, loosen joints and impair the strength of the whole structure. Since the largest room for economy is evidently in the direction of preventing the wholly useless waste at present occurring, the effort should be to keep the maximum temperature as low, and not to push it as high, as possible.

ERICSSON'S ENGINE.

The engine of Mr. Ericsson is too generally known to need many words. In its present form it differs essentially from that which it had when constructed on a large scale, some fifteen years ago, to be employed as the motive power of a sea-going vessel; or, more properly, the present one is a different machine. In the original model a working cylinder was placed immediately over the fire of the furnace, and a cylinder of supply of about two-thirds the capacity was placed immediately over that. The engine was single-acting, the working cylinders were quite open, and the working pistons were of great bulk and formed of non-conducting substances, being designed to fill the cylinders when at the point of the lowest depression, so as to prevent their cooling by contact with the air of the atmosphere. The bottom of each cylinder was arched, forming a dome for a furnace; and the piston received, at its lower surface, a corresponding figure. The pistons of the supply cylinder and working cylinder were firmly connected, and had therefore an equal length of stroke. At the descent of the piston the supply cylinder was filled by aspiration from the atmosphere; and in the ascent the charge, after undergoing compression, was driven into a reservoir, from which it passed subsequently into the working cylinder. The upward stroke being completed, the heated air escaped through a regenerator formed of wire gauze, depositing there its excess of heat; and the new charge from the reservoir, passing to the working cylinder through the same regenerator, re-absorbed this heat, and thus entered the heating chamber already at an elevated temperature.

This engine, it will be seen, was remarkably simple in construction. It also performed very well in practice, so far as its performance was merely a question of mechanics. But it failed, because the heating arrangements were inadequate to the demand made upon them. Mr. Ericsson did not expect to be dependent on his furnaces for the supply of more than a moderate fraction of the heat which each successive charge of air

was to receive. It was his anticipation that the regenerators would serve to transfer so large a quantity from each charge to the next, that it would be necessary to provide for little more than the always inevitable loss by mere radiation. This anticipation was not realized, and in fact could not be, since no account was taken of the large amount of heat necessarily transformed into work. But there was a cause of failure superadded to this, arising from the difficulty of heating air at all by means of a furnace. Radiant heat produces scarcely any impression upon a body of air through which it passes. The inventors of all the air engines which have been to any degree successful have recognized the necessity of applying their heat as much as possible by conduction and actual contact. Mr. Ericsson himself is no exception, as his engine presented in the Exposition shows. This machine possesses a special interest, from the fact that it was the first of its class to secure for itself a recognized place in the industrial world as a valuable aid to productive power.

In its present form the Ericsson engine fails to present to the observer a combination at first view easily intelligible. It even seems to be characterized by a certain amount of complication, which might suggest greater liability to derangement than ought to belong to a prime mover. A closer examination, nevertheless, will show that the mechanism itself is in fact very simple, and that it is only the rather puzzling consecution of movements which confuses.

Before referring to the figure of this engine, which is given in Plate I, the following general explanation of the mechanical principles of its construction will be understood. Let it be supposed that a piston moves air-tight in a cylinder which is closed at both ends. Call one end of the cylinder A, and the other B. Call the piston also C. In the end A let there be a valve opening inward, and in the end B a second valve opening outward. These two valves open, then, in absolute direction, the same way. Let the piston C, furthermore, have a valve opening in this common direction. Then, if the piston C move toward B, its own valve will naturally close, and that of B will open, because the movement tends to compress the air between B and C. Also the valve A will open at the same time, because the movement tends to rarify the air between A and B. Thus, in this movement, continued to the end of the cylinder, all the air on the side toward B may be expelled; but at the same time the cylinder will be filled on the other side toward A, by the influx of air from without. If the piston C now reverse its motion, both the valves A and B will be closed, because the movement will tend to rarify the air on the side of B, and to condense it on the side of A. But its own valve will be opened by the joint effect of these causes, so that the air will pass freely through the piston; and if the motion continues, will ultimately be all transferred to the side of B. This operation may go on indefinitely.

Now if, on the side of A, the cylinder is closed by a second piston

(which we may still call A,) and not by a fixed cap, both pistons being movable, the same succession of occurrences will take place, only modified by the movements which may be given to A. If C and A both move in the direction of A, both their valves will open, and air from the exterior of the cylinder will pass through both into the space between B and C. If they both move toward B, but C faster than A, then air will enter on the side of A, and flow out on the side of B, the valve C only remaining closed. If both move toward A, but A faster than C, air will still enter the space between C and A, while, in less quantity, it is passing through C into the space between C and B.

Let now the piston A be supposed to occupy a position, say one-third advanced down the cylinder, the piston C being further advanced still, and let the valve of B be secured by a strong spring pressing upon it, so that it cannot be opened without the application of some considerable force; and in these circumstances let the cylinder, and consequently the air contained in it, be heated. The elasticity of the confined air being increased by heat will close the valve in A, and that piston will be moved in the direction of A, until, by the enlargement of volume, the elasticity shall be reduced to equality with that of the external air. If the heat be uniform throughout all the mass of confined air, the valve in C will be equally pressed on both sides. Under these circumstances the piston C could be moved toward A, if there were any means of acting upon it, the air passing through the valve toward B. But if an attempt were made to move the piston itself toward B, it would encounter resistance, because its own valve would be closed by the movement, and the valve of B is supposed to be forcibly held down. Since now the external piston must move in the direction A, it is only necessary that it should be properly connected with a machine, in order that the force exerted by the heated and expanding air may be turned to some practical account.

If, again, at the end of the movement, the air could be immediately cooled without being discharged, the heat could be again applied and the effort repeated. But this not being practicable, the heated air may be allowed to escape by relieving the valve B of the pressure of the spring which confines it, and by causing the piston C to descend to the extremity B of the cylinder. This movement of C not only drives out the hot air, but it draws in through A a fresh supply of cold air; and if A descends simultaneously to the position originally supposed, *i. e.*, one-third advanced toward B, there will be a body of air filling the other two-thirds of the cylinder at the common temperature, ready to be acted on anew by heat.

In this statement is embraced the general principle of the Ericsson engine. What remains is to explain the mechanical contrivances by which the movements of the pistons are governed, and to describe the heating apparatus which is employed to effect the prompt dilatation of the air. Inasmuch as the piston which we have called C is shut up in the cylinder behind A, it is necessary that the rods which give it motion

should pass through A. They do so, being packed by means of stuffing boxes to prevent leakage; and are connected at their external extremities with oscillating levers turning on a fixed centre of motion at their extremities, and kept in motion by the engine. The rod of the external piston, A, which is the driving piston, is also connected with an upright oscillating lever, turning on an axis of motion at its lower extremity, and carrying at its upper a horizontal connecting rod which acts on the crank of the main shaft of the engine. It would be simpler to connect the piston directly with this crank; but if that mode of connection were adopted, the stroke of the piston would have to take place in both directions, forward and back, in equal times. This condition is not favorable to the action of the machine; and inequality in this respect is still more important in the case of the supply piston. The peculiar ingenuity of this machine is in fact manifested most signally at this point. By means of the systems of levers interposed between the pistons and the main shaft, provision is made for the perfect uniformity of the revolution of the shaft, while the pistons on the other hand are accelerated and retarded in such a manner as to fulfil the condition that the aspiration of the charge of air should occupy the minimum of time. The oscillating levers which connect with the piston-rods of the supply piston are kept in oscillation by crank motion from the main shaft, and in their oscillations they displace the inner piston, encountering no resistance but friction. In consequence of the un-uniform and unequal velocities of the two pistons, and their intentional adjustment so that they do not begin and end their course together, the distance between them varies in a manner which is quite important, first to the aspiration of the charge, and secondly to the effectual exposure of the aspired air to the action of the furnace.

It is of course of the highest importance that the positions of the cranks on the main shaft, and those of the axes of motion of the oscillating levers, should be so related to each other as to produce a rapid separation of the two pistons at the beginning of the negative stroke; because this is the time when the aspiration of the charge must take place. During this time, the inner piston, gaining on the outer, will not only draw in the fresh charge, but it will expel the exhausted one; the escape valve being lifted for the purpose and kept raised during all the period of aspiration by means of a cam. When the pistons are at the maximum distance from each other, the aspiration is ended. From this time until the half revolution is complete, the confined air undergoes compression, and the movement is maintained by the fly wheel. In the second half revolution the driving piston is urged by the elasticity of the air which is exalted both by compression and by heat.

The heating is accomplished as follows: The furnace is within the cylinder, at the end which we have called B, where the cylinder is prolonged to receive it. It is of iron and is cylindrical also, a small annular space only intervening between its walls and those of the cylinder. This

space is open to the interior, but is closed at the extreme end; so that it forms in fact a portion of the proper air chamber. To the supply piston C is attached by its crown a sheet-iron cylindrical bell, which enters the annular space just spoken of without touching the walls of the furnace or those of the surrounding cylinder. The valve in C opens above the crown of this bell; but any air which comes through the valve from the side of A can only reach the interior by passing down the annular space between the bell and the cylinder wall, and returning up the annular space between the bell and the wall of the furnace. In making this passage, it will be exposed in a very thin sheet to the action of the furnace heat; a very large proportion of the molecules being brought into direct contact with the heated iron.

That we may understand how this movement of the air is made forcibly necessary, we need only consider the relative movements of the pistons during the period of a complete revolution. At the beginning of the negative stroke, or of the movement of A in the direction of B, the supply piston takes the lead, air enters through the valve of A, and the aspiration is soon complete. The distance between the two pistons, which determines the amount of aspiration, is now of course at its maximum. A next begins to gain on C, but both movements have still for a short time the same (negative) direction. The space occupied by the air is gradually reduced; or, in other words, the air undergoes compression. The piston C reaches the limit of its course sooner than A. It begins to move in the positive direction, while the motion of A is still negative. The valve in C is opened by the pressure, the air passes through and having no other channel descends the annular space outside of the bell and returns by the annular space inside the bell, becoming heated, as above described, in its progress. Presently after this displacement commences, the piston A also reaches its limit of movement, and the direction of its motion becomes positive. But C moves the faster of the two, so that the displacement continues throughout the greater part of the positive stroke. A little before the end, the distance between the two pistons becomes minimum; and they are then nearly in contact. When the revolution is quite complete this distance is slightly increased. Just before this time, C will have recommenced its negative movement, while A continues still to be moving in the positive direction.

The relative movements here described will be more advantageously compared by presenting them in tabular form, which we are enabled to do by the help of the determinations made by Mr. Mastaing, of Paris, upon the Ericsson engine which was made the subject of experiment in 1861 at the *Conservatoire des Arts et Métiers*, by Mr. Tresca, sub-director of that institution. In the first column of this table are placed the angular positions of the driving crank on the main shaft at different periods of the revolution; putting zero to represent the position of the crank when the piston A is about to commence its negative stroke. The

second column gives the direction of motion of the driving piston, and its motion relative to that of the other; and the third column gives the same particulars in regard to the supply piston. The last column gives the variation of distance taking place between the two pistons at the several points indicated in the table.

Angular position of the crank.	Relative motion of the pistons.		Distance between the pistons.
	Driving piston.	Supply piston.	
°			
0 to 70	Negative, losing	Negative, gaining	Increasing.
70	Negative, equal	Negative, equal	Maximum.
70 to 120	Negative, gaining	Negative, losing	Decreasing.
120	Negative, gaining	Limit of course	Decreasing.
120 to 170	Negative, contrary	Positive, contrary	Decreasing.
170	Limit of course	Positive, gaining	Decreasing.
170 to 310	Positive, losing	Positive, gaining	Decreasing.
310	Positive, losing	Positive, gaining	Minimum.
310 to 340	Positive, gaining	Positive, losing	Increasing.
340	Positive, gaining	Limit of course	Increasing.
340 to 360	Positive, contrary	Negative, contrary	Increasing.

It will be seen that the negative stroke is completed in less than half a revolution, for either piston, while the positive stroke requires more; also, that this inequality is considerably greater for the supply piston than for the driving piston. In the case of the driving piston the inequality is as 170° to 190°; in that of the supply piston, as 160° to 200°. These inequalities, which could not exist if the connection between the main shaft and the pistons were made directly, as in the steam-engine, are the effect of the intermediate system of levers, and are intentionally produced. The increase of distance between the pistons from 310° to the end of the revolution is not an advantage, but it is not a great increase, the total distance amounting finally only to about the one-sixth part of the maximum separation, and receiving the principal accession to its amount between 350° and 360°. As after the second reversal of the movement of the supply piston, the effective power of the engine is necessarily paralyzed, the escape valve is opened at 344° by the action of the cam above spoken of, and the aspiration commences before the revolution is quite complete. The valve is closed again at 69°, just as the aspiration is becoming maximum.

Inasmuch as the effective power of this engine is negative or zero from 344° onward to 170°, or through a little more than half a revolution, it is necessary that the machine should be provided with a heavy fly-wheel to maintain the movement during these intervals. The fly-wheel is made to act also as a sort of counterweight, as well as by means of its moment of rotation, the side of the wheel which is descending during the period

of paralysis being made considerably heavier than the other. A companion engine to act positively during the inaction of the first, would render such an expedient unnecessary; but unfortunately the bulk is considerable relatively to the power, and it would, in general, be a disadvantage to double it.

The engines of Mr. Ericsson are largely in use in the United States; but as yet they have not been constructed of any considerable power. As a general rule they fall within three or four-horse power as an outer limit; though it is believed that there have been made some exceeding this limit. On account of their safety and convenience they have been regarded with favor; and it has been claimed for them as an additional recommendation that they are economical. Such did not appear to be the fact in the case of the particular engine which was the subject of the experiments of Mr. Tresca above referred to. In this machine, which was of two-horse power, the result of very careful trial showed a consumption of 4.13 kilograms (about nine pounds) of coal per horse-power per hour. In comparison with steam this cannot be called a large economy. The consumption of a good steam engine ought not to exceed, per horse-power per hour, two kilograms at the outside. One and a half ought to suffice.

It may be observed, in conclusion, that Mr. Ericsson makes no attempt to carry the temperature in this engine to a very high point. The mean maximum temperature in the experiments at the *Conservatoire* did not exceed 270° Fahrenheit, though doubtless portions of the air received a greater degree of heat than this. The expansion of volume was further determined to be but as 1 : 1.48—that is to say, about fifty per cent. of the original bulk.

The general description here given will be made more intelligible by reference to the figures of the engine given in Plate I. One of these, Fig. 1, is a longitudinal section through the axis; and the other, Fig. 2, a cross-section through the furnace.

Of the two pistons shown at A and F, the first, A, is the driving piston, and the second the supply piston, which in the foregoing explanation we have called C. In A is seen a valve marked *a*.

At B is an axis of motion, the office of which is to communicate movement to the piston A, by means of a crank *o*, a connecting rod *p*, a second crank *q*, and another rod *r*.

In the piston F the valve of communication is shown at *f*. The solid portion F′ is filled with plaster or other badly conducting substance, while F″ marks the bell-shaped prolongation which extends into the annular space surrounding the furnace. When by the approach of the piston F to the piston A, the space between these two pistons is reduced, there is no escape for the air between them but that which is afforded by the annular cavities between this bell and the external wall of the machine *f′*, on the one hand, and the wall of the furnace itself on the other. The air passes first along the outer space to the mouth of the bell,

and returns through the inner, forming a thin stratum in immediate contact with the hot wall of the furnace.

Another axis of motion is shown at C, of which it is the office to communicate movement to the supply piston F, through the crank *o*, the connecting rod *s*, and the cranks *t* and *u*, which last two are fixed to the arbor C, at a fixed angle to each other of seven degrees.

The escape valve is placed at D, and kept in position by the spring *d*. A cam D′, acting on this valve through the lever D″, opens it just before the driving piston commences its descent at the end of the positive stroke.

The furnace is enclosed in the iron box G, the grate bars being shown at *g*. G′ indicates plates of iron designed to protect the walls of the furnace.

In order to bring the two pistons into a favorable position for starting, the fly-wheel is turned on its axis; and, for the purpose of facilitating this operation, the arbor K is introduced, which enables the attendant to act on the fly by means of the clicks marked *k*, and the notches *k*′.

The furnace door *l* is made double to reduce loss by radiation. The walls of the furnace are similarly protected by means of a double envelope.

The products of combustion escape from the furnace through the flues *h*, protected by fire-brick, and are carried off by the chimney H.

SHAW'S ENGINE.

The hot-air engine of Mr. Shaw, of Boston, which was in operation in the park of the Exposition, received much attention, though its merits seem not to have been justly appreciated by the jury. This engine, according to the statement of the exhibitor, is of 20-horse power; but no particulars are given of the actual experimental trials on which this estimate of its capabilities is founded. Its principal parts are a furnace, cylindrical in form, of boiler iron, lined with refractory brick; two single-acting cylinders working alternately; and a regenerator, which consists of a chamber filled with tubes similar to those of a tubular boiler, through which the exhaust air escapes. The air is heated in the furnace immediately in contact with the fuel, of which it at the same time supports the combustion. This furnace is accordingly closed air-tight, fuel being supplied when necessary by means of a box or receiver on the top, between which and the interior of the furnace communication can be opened; the box itself being, in the mean time, tightly closed. From the furnace the air, along with the gaseous products of combustion, is admitted beneath the pistons of the working cylinders alternately; and after it has performed its function, it is discharged through the tubes of the regenerator into the chimney. The upper portions of the working cylinders are employed to furnish the supply of cold air from the atmosphere. For this purpose each piston is provided with a trunk considerably smaller in diameter than the cylinder; and the annular space between the trunk and the cylinder, being closed in at the top, forms an air pump. As the piston descends, the air of the atmosphere enters this annular

space through valves opening inward; and on its ascent this air is forced into the regenerator, where it becomes partially heated by contact with the tubes through which the dilated air is escaping, and thence passes into the furnace.

The brick lining of the furnace is double, with a space between the walls; and this space the entering air from the regenerator is obliged to traverse before it reaches the fire. Its temperature, which is already somewhat raised by compression and by contact with the tubes of the regenerator, becomes still more elevated in its passage through this space; and the additional heat which is wanted to bring up the pressure to the point required is supplied by the fuel. In this engine, the difficulty which impeded the success of most of the earlier machines of its class, viz., the failure to secure an adequate heating of the air, is effectually overcome. The heat developed by combustion is necessarily taken up by the air which supports the combustion, and by the gaseous products at the same time generated. It is not surprising, therefore, that Mr. Shaw has found it practicable to maintain a pressure under his pistons which averages about an atmosphere. But it must be observed, nevertheless, that such a pressure can only be secured by carrying the temperature to a point which must be destructive of lubricants and of packing, and must increase the difficulty of preventing leaking as a consequence of unequal expansion.

The construction of the engine here described will be made more clear by reference to the figures in Plate I. In Fig. 1 the engine is seen in elevation. From this will be obtained a very correct idea of its general appearance. Fig. 2 is a section in elevation, and Fig. 3 a horizontal section. Fig. 4 is a section of the regenerator. The same letters in the different figures are designed to indicate the same parts. A A are the cylinders. B indicates one of the pistons in section, and B′ the corresponding trunk. C is the passage to the regenerator, and D the annular space forming the air pump. E is the induction valve, and F the eduction valve. M is the space beneath the grate; N the surrounding fire-brick, and M′ the space behind the fire-brick which the air passes through on its way from the regenerator to the fire. M^3 indicates the grate itself. R is the passage from the furnace to the cylinder, and P is the escape for the exhaust air. In the horizontal section the regenerator is marked V. The ash door is shown at *f*; the chamber for the supply of fuel at *a*.

The engine exhibited embraced two cylinders, each single-acting, but acting alternately. This construction makes the power always positive. The dimensions as given were: diameter of the piston, twenty-four inches; diameter of trunk, fifteen and a half inches; length of stroke, eighteen inches. Available pressure, fourteen pounds to the square inch. Number of revolutions, sixty per minute.

With these data the power of the engine may be easily calculated. It was claimed to be of twenty horse power; but this is a pretty large over-estimate, even allowing, which is doubtful, that the asserted pressure of fourteen pounds per square inch can be safely employed.

We have—

Area of piston .... 452.4 square inches.
Double this for two pistons .... 904.8 square inches.
Length of stroke .... 1.5 foot.
Initial pressure per square inch 14 pounds + 15
pounds (pressure of atmosphere) .... 29 pounds.

Economy requires that the pressure of the exhaust air shall not exceed that of the atmosphere. The induction valve must therefore be closed at the point proper to produce the required reduction of elasticity by the expansion of the confined air. This point may be found by applying the formula of Poisson, expressing the relation between the elastic force of a gas undergoing change of bulk and its corresponding volume, which is

$$\frac{p_1}{p_0}=\left(\frac{v_0}{v_1}\right)^{\gamma}, \text{ or } \frac{v_0}{v_1}=\left(\frac{p_1}{p_0}\right)^{\frac{1}{\gamma}}$$

in which p_0 and v_0 are the original pressure and volume of the gas, and p_1 and v_1 are the pressure and volume after the change; while γ is the thermo-dynamic index of the gas, or the ratio between the specific heat at constant pressure and the specific heat at constant volume. In the case of air, $\gamma=1.421$.

The volume of the air will be equal to the product of the area of the piston by the distance between it and the end of the cylinder which forms the opposite side of the chamber within which the air is confined. At the end of the stroke this distance will be equal to the entire course of the piston, and may be represented by l_1. At the moment of cut-off, it will be the partial length of stroke which the piston has so far accomplished, and may be denoted by l_0. Then we shall have—

$$v_0 = al_0;\ v_1=al_1;\ \frac{v_0}{v_1}=\frac{al_0}{al_1}=\frac{l_0}{l_1}=\left(\frac{p_1}{p_0}\right)^{\frac{1}{\gamma}}$$

$$\text{and hence, } l_0=l_1\left(\frac{p_1}{p_0}\right)^{\frac{1}{\gamma}}=1.5\left(\frac{15}{29}\right)^{\frac{1}{1.421}}=0.943.$$

Completing the numerical operation, we find that the cut-off should be applied at a little short of two-thirds of the stroke. For the work done before the cut-off, which may be denoted by W_0, we have—

$$W_0=ap_0l_0=904.8\times 29\times 0.943=24{,}750 \text{ foot-pounds,}$$

which is the work of one revolution, a representing the area of both pistons.[1]

The work done during the dilatation of the air, which may be denoted

[1]The formula given in the note on p. 31, for the theoretic case there considered, cannot be applied to this computation. In the present case the mechanical conditions are such as to require that the pressure should be constant during the second third of the stroke at least; and it cannot well be greater either before or after. To assume that the pressure is constant and maximum up to the moment of the cut-off is as nearly as possible correct, and so far as it may be otherwise is favorable to the engine.

by W_1, may be computed by means of an expression deduced from Poisson's formula above, viz:

$$W_1 = \frac{ap_0l_0}{\gamma-1}\left(\frac{l_1^{\gamma-1}-l_0^{\gamma-1}}{l_1^{\gamma-1}}\right) = \frac{904.8\times 29\times 0.943}{0.421}\left(\frac{1.186-0.976}{1.186}\right) = 10{,}428 \text{ foot-p'ds.}$$

And if W is the total work,

$$W = W_0 + W_1 = 24{,}750 + 10{,}428 = 35{,}178 \text{ foot-pounds.}$$

To this are opposed three resistances, which must first be deducted before the available power of the engine can be known. The first is the resistance opposed by the air during compression, which, being analogous to the positive power exerted during dilatation, may be denoted by R_1. The second is the constant resistance which takes place while the air is being driven into the regenerator, which may be called R_0; and the third is that due to atmospheric pressure upon the trunk, which we will represent by R_2. R_0 and R_1 are simply the inverse of W_0 and W_1, differing only in proportion to the area of piston surface upon which they are exerted.

And as we have—

Double area of working piston (as before,) .... 904.8 square inches.
And also, double area of trunk section .... 377.4 square inches.
We have by, subtraction, double area of annular
section .... 527.4 square inches.

So that, putting a_0 for the first double area, and a_1 for the last, there will result the values following:

$$R_0 = \frac{a_1}{a_0} W_0. \quad R_1 = \frac{a_1}{a_0} W_1.$$

Whence $R_0 = 14{,}426$ foot-pounds and $R_1 = 6{,}078$ foot-pounds. Putting the double area of trunk section, a_2, the atmospheric resistance will be

$$R_2 = 15a_2l = 8{,}491 \text{ foot-pounds,}$$

l being the total length of stroke. Whence, finally,

$$R = R_0 + R_1 + R_2 = 28{,}995 \text{ foot-pounds;}$$

which deducted from 35,178, the value of W, leaves 6,183 foot-pounds as the balance available for work exterior to the engine during a single revolution.

For sixty revolutions this becomes 360.98 foot-pounds per minute; and taking 33,000 foot-pounds per minute as a measure of one-horse power, we find the aggregate horse-power at length to be 11.24, or about eleven and a quarter. From this must be deducted the passive resistances, which will reduce the available horse-power below eleven. It is possible that a more rapid revolution can be maintained; but hardly possible that the number can be carried up to one hundred and twenty, which would be necessary to increase the horse-power to twenty, as claimed.

The temperature to which the air must be raised in order to secure, under the circumstances, a pressure of fourteen pounds to the square inch may also be computed. The elasticity of a gas is proportional to

its density, and to its temperature measured from the absolute zero, (say from —460° F.) If the temperature of the weather at the time of experiment is 60° F, this will be 520° above the absolute zero. Putting P for the maximum pressure, p for the minimum, (that of the atmosphere,) D for the maximum density, and d for the minimum; and, finally, T for the temperature at maximum pressure, and t for the same at minimum, we shall have,

$$\frac{P}{p}=\frac{TD}{td}$$

The densities are inversely as the volumes; and the volumes are measured by the products of the cross-sections of the spaces they occupy into their lengths in the direction of movement. Let these be denoted for the time of maximum pressure by A and L, and for that of minimum by a and l. Then

$$\frac{D}{d}=\frac{AL}{al}, \text{ and } \frac{P}{p}=\frac{ALT}{alt},$$

$$\text{Whence } T=\frac{Palt}{pAL}.$$

From what has gone before it appears that $P=29$ pounds, $p=15$ pounds, $a=527.4$ square inches, $A=904.8$ square inches, $l=1.5$ feet, $L=0.943$ feet, and $t=520°$. By substituting those numbers in the expression above, we find,

$$T=932°, \text{ and } 932°-460°=472° \text{ F},$$

which last number is the temperature to which the whole body of the air must be raised; or the temperature at least which it must have in the cylinder. At the moment of leaving the furnace it can hardly be below 500° F. This determination is so high as to justify the doubt above expressed as to the safety, to the lubricants and packing, of attempting to maintain so high a pressure.

It is claimed by Mr. Shaw that his engine is more economical of fuel than any steam-engine; but no experimental statistics were given in support of this assertion. The machine is however so compact and so easily managed as to produce a very favorable impression; and it is to be hoped that the claim to economy may prove to be well founded.

What was the actual pressure during the performance at the Exposition could not be determined, as no manometer was observed in connection with it; and as it was doing no work its capabilities could only be judged of conjecturally. It was a very conspicuous object in the section of the park occupied by the United States, and was constantly surrounded by a crowd of interested observers.

BELOU'S ENGINE.

Mr. Shaw is not the only inventor who has sought to avail himself of the very effectual mode above described of securing the thorough heating of air. A patent was taken out in 1860 by Mr. Belou, a French engi-

neer, for an engine of which the motive power was obtained in the same manner, but which differed from Mr. Shaw's in several particulars. In the first place, it employed but one working cylinder, of which the piston was double-acting. It had, secondly, an independent supply pump, also double-acting; and it differed, thirdly, from Mr. Shaw's engine, in having no regenerator. The working cylinder was, however, provided with a jacket, between which and the cylinder itself the air circulated in passing from the supply pump to the furnace; becoming thus partially heated.

As Mr. Belou's engine has been subjected to careful tests of its performance in regard to economy, conducted by Mr. Tresca, the able subdirector of the *Conservatoire des Arts et Métiers*, it may be interesting, in the absence of corresponding data in regard to the engine of Mr. Shaw, to present here the results. The first trial was made on an engine of very nearly four horse-power, as determined by a Prony dynamometer. The consumption of coal per horse-power amounted to 2.64 kilograms per hour. It appeared, however, from the indications of the pressure-gauge, that the actual power developed in the cylinder amounted to more than five times as much, or to twenty-two-horse power.

From a careful determination of the sources of loss, it was shown that more than forty-four per cent. of the whole power was expended in overcoming passive resistances, and thirty-three and a half per cent. in compressing the air for the supply—there remaining only about twenty-two per cent. available for use. By a series of observations on the temperature of the escaping air, it was further found that about one-half of the heat developed by the combustion of the fuel was lost without any effect at all. These experiments were made in Paris in 1861.

In 1866 a much more powerful engine by the same inventor was subjected to a series of experiments by Messrs. Tresca and Alcan, in a paper manufactory at Cusset, of which it had been erected as the driving power. The working cylinder of this engine had a capacity of about eighty cubic feet; that of the supply cylinder was about half as great. In this case the amount of force developed, as measured by the indications of the manometer, was equal to one hundred and twenty-horse power, but of this the supply absorbed eighty-horse power, or two-thirds of the whole; and more than ten-horse power was estimated to be necessary to overcome the passive resistances. Less than thirty-horse power, therefore, or one-quarter of the whole, was actually utilized. The consumption of coal was about forty kilograms per hour; or, according to the calculation of the experimenters, 1.46 kilograms (three pounds) per horse-power per hour. This performance places the engine about upon a par with an economical steam-engine. It is to be observed, however, that the heat was carried to a height which could not but tend to deteriorate rapidly the parts of the engine exposed to it; and especially the interior of the working cylinder. In order to protect this surface, it was constantly lubricated with a solution of soap in water, of which about five gallons were consumed

per hour. The great heat imparted to the air rendered inevitable also a very large final loss. It was made evident by very conclusive experiments that the air in the chimney was at least 250° Centigrade (450° Fahrenheit) above the temperature of the atmosphere, and it is computed by Mr. Tresca that fully seven-eighths of the heat produced by the fuel was expended unproductively.

Notwithstanding this, the fact that the engine, after all, performed as economically as the best steam-engines, is eminently encouraging to those who hope to see steam-power advantageously replaced by something safer and more universally available. This view is taken in an interesting paper presented to the Academy of Sciences of France by Messrs. Burdin and Bourget in the year 1863. The paper here referred to maintains the practicability of carrying the heat in an air-engine to a very high temperature, and of securing such a temperature by a very economical process of heating. It is proposed to heat the air in a furnace, but not in contact with the fuel, by means of an assemblage of tubes passing through the fire. Various expedients are suggested for securing the parts of the engine which are exposed to high heats, or for protecting against their injurious effects; and it is supposed that the temperature of the air may be raised advantageously as high as 600° Centigrade. It is at the same time admitted that one-half of the heat of the fire will escape directly through the chimney.

With these data the authors present a series of calculations founded upon formulæ derived from the mechanical theory of heat, by which it would appear that heated air ought not to require, in a properly constructed engine, more than one-third of a kilogram of coal per horse-power per hour. This economy, however, is yet far from being realized; and the disadvantages attendant on the use of extremely high temperatures, some of which have been mentioned above, make it very improbable that it ever will be.

Mr. Shaw's engine ought to be more economical of heat than that of Mr. Belou, inasmuch as the regenerator must save a considerable portion of the excess of heat of the escaping air. The claim of its inventor, that its consumption of fuel is less per horse-power per hour than that of the best steam-engine, may possibly be well founded.

Mr. Belou's engine is represented in Plate II, Figs. 1 and 2. The first is a general plan of the machine, and the second a vertical section passing through the axes of the two cylinders.

A marks the furnace or fire-box, at the extremity of which is seen the hopper, or receptacle for fuel, marked B.

The working cylinder is represented at D, and the supply cylinder at E.

The air, in passing from E to the furnace, passes through the space *d* between the working cylinder and its enveloping jacket. Provision is made by which a portion of the air, larger or smaller, as occasion may require, may be made to pass into the furnace over the fuel, and not

through it. By this means the intensity of the heat may be varied, and the working pressure increased or diminished.

M is the main shaft, N the fly-wheel, and Q Q′ connecting rods which explain themselves. The fly-wheel on the large engine at Cusset weighs about fifteen tons.

The fuel introduced into B is spread over the grate by a mechanical contrivance operated by the arbor B′, which is connected with an eccentric on the main shaft.

The small machine, first made the subject of experiment by Mr. Tresca, was provided with a reservoir for containing a reserve of compressed air to be employed in starting the machine; for, every air-engine, whether double or single acting, has to contend with a resistance exceeding the power during a portion of the stroke. The machine at Cusset was without such an auxiliary, but was put in motion by means of a turbine of fifty-horse power, which was employed to drive it for a few revolutions, after which it regulated itself. The trouble of starting is one of the disadvantages of all motors of this class. When the power is small the fly-wheel may be turned by hand, or by some mechanical contrivance, such as is provided in Mr. Ericsson's engine; but when it is comparable to that of the great engine at Cusset a reserve is necessary. This may be furnished by a reservoir of condensed air, provided very great care be taken to prevent leakage. The experience of the engineers engaged in constructing the tunnel under the Alps shows that air under heavy pressure may be kept for weeks in metallic reservoirs without sensible loss. The experience of Mr. Belou seems to have been different, since after having adopted this expedient he abandoned it for another.

The observations do not show the maximum temperature which was imparted to the air; but the fact that the exhaust at the top of the chimney was at 250° Centigrade, (482° Fahrenheit,) shows that it must have been excessive. The mean pressure was not, however, very great. The induction valve was closed at four-tenths, and the air acted expansively through the remainder of the stroke, the pressure falling to equality with that of the atmosphere at the end.

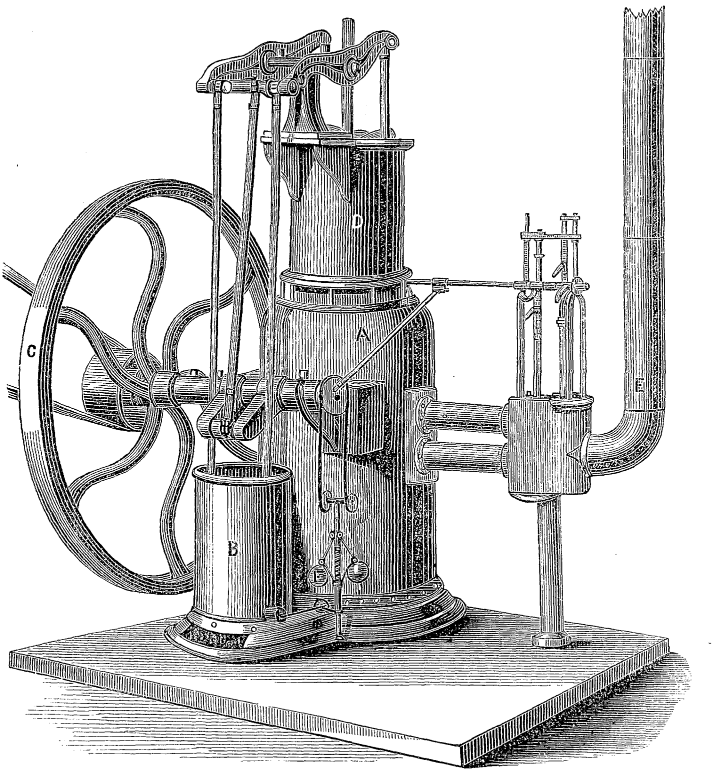
We must conclude, upon the whole, that in this machine, it is practically demonstrated, not only that heated air can be made successfully a source of motive power, but also that this can be done economically and upon a large scale. As being the first in which these several propositions have been fully established, this engine cannot but be regarded with peculiar interest.

ROPER'S ENGINE.

In the American annex was exhibited a hot-air engine by Messrs. Crosby, Butterfield and Haven, of New York, under the name of Roper's engine. This was not at any time in operation, nor was there any attendant present to explain its peculiarities, although it was the subject of a good many inquiries on the part of visitors. Its principal

organs were, however, sufficiently recognizable, and the compactness of its arrangements appeared to be such as to adapt it very advantageously to small industrial operations. The furnace in this engine is a cast-iron cylinder lined with fire-brick. Immediately over the furnace, and apparently formed in the same casting, is the working cylinder, smaller in diameter than the furnace and open above. The piston rod is kept vertical by means of a guide, and two connecting rods attached to the piston, one on each side of the proper piston-rod, are attached to balance levers which are united at their opposite ends by a cross-bar, to the middle of which is attached the connecting rod which turns the crank of the main shaft. The balance levers are pivoted in supports which are secured to the working cylinder itself, and they carry, also, a pair of rods which operate the piston of the supply cylinder. The supply cylinder is immediately under the working shaft, and is as conveniently near the furnace as practicable, standing upon the same base with it. The furnace is air-tight, and the air supply is forced into it beneath the

Fig. 2.



ROPER'S HOT-AIR ENGINE.

grate, passing through the fuel, and so upward into the working cylinder. Provision is said to be made to divide the air current in such a

manner as to allow a portion of it, at pleasure, to enter the furnace above the fuel, for the purpose of regulating the rapidity of combustion and the temperature of the charge in the cylinder, but the contrivance by which this is effected was not exactly understood. The exhaust air with the products of combustion is discharged through a pipe communicating with the chimney of the building. The main shaft carries a heavy fly-wheel to maintain the motion during the downward stroke and during the period of greatest compression of the supply. The same shaft carries a pulley by which the power is applied. The whole machine occupied on the ground a space of about five or six feet square. The power could not be ascertained.

An engine so similar to this as apparently to be identical with it was seen in London after the Exposition, where it is sold by the manufacturers, Edwards & Co., of Oxford street, as their own invention. This is shown in Fig. 2.

The cylindrical furnace is indicated by the letter A. At B is seen the supply cylinder. C is the fly-wheel, D the working cylinder, and E the escape pipe. F is a governor which acts upon the valves in the interior by means of levers, cams, and rods, indicated in the figure, and of which the effect is to vary the quantity of air passing through the fuel, and to cause a greater or less portion of it to enter the furnace above.

The manufacturers say that this engine is intended to be used only with anthracite coal. With a consumption of eight pounds of coal per hour its performance is equal to three-horse power.

No provision is here made for introducing the fuel while the engine is in operation. Interruptions will therefore occur from time to time in order to replenish the fire; but these, it is stated, will not consume more than twenty minutes during a working day of ten hours. In starting the machine it is necessary, as in the use of the engines previously described, to turn the fly-wheel for a few revolutions by hand. And it is also necessary that the fire shall be well lighted before the door of the ash-pit is closed.

The peculiar merit of this engine is such an arrangement of parts as to reduce the bulk to a minimum. In order to accomplish this the regenerator is excluded, and no attempt is made to secure a partial heating of the supply, as in the Belou engine, by causing it to circulate in contact with the heated walls before entering the furnace. The statements therefore in regard to the consumption of fuel per horse-power are remarkable; and it is to be desired that some careful experimental determinations should be made of the actual performance, as tested by the dynamometer, in order to verify their accuracy.

LAUBERAU'S ENGINE.

The only engine present in the Exposition constructed on the principle of the displacement of a body of confined air which, without being discharged, is subjected to alternate extremes of cold and heat, was exhibited

by Mr. Lauberau, an inventor of Paris. In this machine a certain volume of air is enclosed in a cylinder of metal, in which there is also a large moving plunger which, by occupying alternately one end and the other of the cylinder, drives the air in like manner in the opposite direction. The upper portion of the cylinder is surrounded by a jacket, between which and the cylinder itself there is maintained a constant circulation of cold water. The design of this is to absorb the heat which the air may bring with it, when, by the descent of the plunger, it is forced to enter this space. As the plunger itself is but slightly less in diameter than the interior of the cylinder, the air during the transfer is reduced to a thin cylindrical stratum, and is brought into close contact with the cold walls. The effect of the engine depends as much upon the efficiency of this cooling process as upon the subsequent heating, and therefore it is desirable that the water of refrigeration should be as cold as possible. But as this water must necessarily be drawn from natural sources, it is obvious that the engine will be more efficient in winter than in summer.

The lower portion of the cylinder is occupied by a furnace which, in all material respects, resembles the furnace of the Ericsson engine already described; that is to say, it is a cylinder, smaller than the air cylinder, leaving an annular space between its walls and those of the latter. The plunger also, like the piston plunger of the Ericsson engine, is provided with a bell-shaped continuation, which enters the annular space around the furnace. If we suppose the plunger in the lowest position it can occupy, that is in the end next to the furnace, the air will be in the upper end of the cylinder, and in contact with the walls which are kept cold by the water circulating around it. As the plunger rises, the air, being compressed, seeks to escape, and is forced to pass down the annular space between the bell and the outer wall of the cylinder at bottom, and afterwards up between the same bell and the hot walls of the furnace. It thus becomes rapidly heated, and its pressure rises; but this does not affect the motion of the plunger, which is pressed equally above and below. The pressure is utilized by means of a second and smaller cylinder, provided with a piston which is connected with the crank of a working shaft. The lower part of this cylinder communicates with the heated extremity of the air cylinder. The air expanding under the influence of the heat, passes into the small cylinder and raises its piston. When the plunger descends, the effects are the reverse of those just described. The air is driven into the cold end of the cylinder and contracted by cooling, and the piston of the working cylinder also descends. It is understood of course that the movements of the plunger are determined by those of the working piston; and as this piston is single acting, during one-half of the revolution the machine exerts no power. It must therefore be started by turning the fly-wheel once or twice by hand. After that, if the heat is up in the furnace, it will continue to act without further attention. The circulation of cold water is kept up by means of a pump which derives its force from the working shaft. In the very small models constructed by Mr. Lau-

berau, of less than one-half-horse power, this pump is very simple, being merely a small round box into which a solid plunger enters through a stuffing box.[1] In the larger, the refrigerating part of the cylinder, as well as the heating, is furnished with an annular extension, while the plunger-displacer carries a bell at each end. In these also an economy of heat is secured in the construction of the furnace, by giving it an exterior wall between which and the surface to be heated the flame and gaseous products of combustion are forced to circulate on their way to the chimney. Two working cylinders have also been employed instead of one, by means of which a more equal performance is maintained, and the weight of the fly-wheel is reduced.

This engine, which seems admirably adapted to small industries requiring but a fraction of a single horse-power, is not, however, very economical. From experiments made at the *Conservatoire des Arts et Métiers*, in 1863, upon a Lauberau engine of four-fifths of one-horse power, it was found that the consumption of coal was equal to 4.55 kilograms (nine or ten pounds) per horse-power per hour, while the refrigeration required 700 kilograms (180 gallons) of water per hour also. It is not to be understood, however, that this great quantity of water has to be constantly renewed, or that it must be necessarily suffered to run to waste. If the quantity is sufficient to allow some interval between its discharge from the refrigerator and its return to the refrigerator again, it will be brought back, by natural cooling, to a temperature sufficiently low to allow of its repeated use.

This machine, though not abstractly economical, may in certain circumstances be practically so. It is adapted, better than any other thus far presented, to domestic uses for which very small power is required, as it is portable and compact, and can run by means of a gas lamp very well. Though it will not work so cheaply as a steam-engine, it may perform certain tasks more cheaply a great deal than human labor could do, and it may thus be a source of a relative economy which is very real.

The Lauberau engine which was the subject of the experiments of Mr. Tresca, is represented in Plate II, Figs. 3, 4, 5 and 6. Fig. 6 is a vertical section made through the axis of the displacement cylinder. Fig. 4 is a general plan. Fig. 5 is a cross-section exhibiting the details of the working cylinder and of the furnace.

A is the working cylinder with the working piston a, acting on the arbor G by means of the connecting rod g and the crank g'.

B B′ is the displacement cylinder, and b the plunger. The plunger is formed of non-conducting material, and carrries at its two extremities the bell-shaped or cylindrical prolongations which enter the annular spaces b' and b''. This piston is acted on by the connecting rods H and h. A roller, or friction wheel, r, sustains the weight of the piston

[1] In some models this feed pump is more simple still, being merely a little metallic cup, closed by a membrane of caoutchouc, which being attached by its middle point to a rod moved by a little crank, rises and falls with a movement resembling the beating of the heart.

and its connections during the movement. This turns on its axis in a closed cavity communicating with the cylinder at the point of support only.

C is the furnace, with a grate adapted to coke or charcoal. A flue is indicated by the letter *c*, in which the gaseous products of combustion may circulate around the annular space b' before escaping by the chimney. The air, in passing from one end of the cylinder B B' to the other, takes necessarily always the annular spaces b' and b'' in its course.

F is a tube which permits free communication constantly between the displacement cylinder B B' and the working cylinder A through the annular space b'.

E is the chimney provided with a damper, *e*.

G G' are furnace doors for introducing fuel and regulating the draught.

V is the fly-wheel.

K is the tube through which the water of refrigeration is introduced within the jacket surrounding the cold end of the displacement cylinder, and K' the passage of escape for the water after having circulated through this space.

M is a lever serving to enable the attendant to open the valve *m*, which establishes communication between the cylinders and the atmosphere.

Finally, *n* is a snifting valve opening into the cold extremity, by which the loss of air by escape through the packings is compensated.

In the small engines on this plan the displacement cylinder is vertical, and a powerful gas lamp takes the place of the grate. A representation of one of these is given in section in Fig. 6. A is the working cylinder; B, the working piston; D, the piston displacer; E, the furnace space, showing the section of the gas-burner; F, the cold-water jacket. The other parts will explain themselves. The products of combustion pass downward between the wall of the furnace and the inner wall of the annular cavity in which the air is heated, and pass off through a flue opening toward the left in the figure, beneath the working cylinder. Some of these machines are hardly a cubic foot in dimensions, and they vary in power from a sixth to a thirtieth of a horse-power. Their neatness and portability are very much in their favor, as well as the extreme promptness and facility with which they are set to work. One of the most amusing displays during the early days of the Exposition was a little boat, six or eight feet long, which ran along the shore of the Seine, in front of the Champ de Mars, driven by a Lauberau engine of perhaps an eighth of a horse-power. It was too small to carry a passenger, but made its trips from point to point, according as it was directed by the attendant.

WILCOX'S ENGINE.

The foregoing enumeration embraces all the hot-air engines presented at this Exposition. There was one from the United States exhibited at London in 1862, which was esteemed there worthy of a medal, and which

was distinguished by some peculiarities deserving of notice, by way of comparison with those above described. This was the Wilcox engine, of which the peculiarity consisted in the employment of two working cylinders through which the air successively passed. The furnace was in the lower portion of one of these cylinders, and the supply pump was in the upper chamber of the same cylinder. The engine was further provided with a regenerator of thin metal plates. The air, after being compressed in the supply pump, passed through the regenerator, taking up the heat left there by the last charge of escaping air, and thence into the second working cylinder. In this it produced a partial effect, due to the heat already absorbed, and then entered the first or principal working cylinder, where it received the heat of the furnace. The advantage of admitting the supply air to the cylinder which contains the furnace is very considerable, as it tends to prevent that cylinder from being overheated, while it utilizes the heat which would otherwise be injurious.

FRANCHOT'S ENGINE.

Another machine was exhibited in model, in 1855, at Paris, so ingenious in its conception that it has been made the subject of an elaborate theoretic discussion by Mr. Combes, of the Imperial School of Mines, in his excellent work on the mechanical theory of heat. This was the invention of Mr. Franchot, of Paris. It consisted of two cylinders, entirely equal, and both of double effect, of which the pistons were connected with cranks on the same working shaft. One of these cylinders was to be kept constantly at the maximum temperature, and the other at the temperature of the ambient air. The mode of maintaining the superior temperature was not perhaps satisfactorily settled, since Mr. Franchot has never executed his project on a large scale. Between the two cylinders communication was always free, both above and below their respective pistons; the air passing from one to the other alternately, as the pistons moved. But the body of air above the pistons was permanently separated from that below them. These two bodies of air, therefore, having been originally equal in mass, always remained so, though their volumes were constantly changing. Regenerators were placed both at top and bottom, in the space through which the air had to pass in its passage from cylinder to cylinder. In these regenerators it was designed that the air should leave its heat in passing from the hot cylinder to the cold; and it was presumed that it would take the same heat up again, in its return from the cold cylinder to the hot. Finally, in the attachment of the pistons to the working shaft, the arrangement was such that the crank of the hot cylinder piston was always ninety degrees, in the direction of revolution, in advance of the other. By considering the movements of the piston under these circumstances, we may easily discover what must be the maxima and minima of the effective force of the engine, and the progress of the fluctuations of the force. For convenience, let the piston of the hot cylinder be called A, and the other B.

Then if A is in the middle of its course, descending, B will be at the uppermost limit of its course, and about to descend. All the superior mass of air will be in the cylinder A, and in the upper regenerator; and, disregarding the regenerator, we may say that it is reduced to one-half its normal bulk. By the law of Mariotte, its pressure would be doubled; but by the added effect of the elevated temperature which, for facility of illustration, we will suppose to be sufficient to double its elasticity, it will be quadrupled; so that, at the instant in which B begins to descend, there will be a downward pressure on both pistons of four atmospheres. At the same time the inferior mass of air will be expanded to once and a half its normal bulk, and its pressure would be equal to two-thirds of an atmosphere only, but for the high temperature of the part which occupies the lower half of the cylinder A. The actual inferior pressure will be something more than four-fifths of an atmosphere, and the excess of downward over upward pressure will be upward of three atmospheres. At this time, however, the motion of the piston A is much more rapid than that of piston B, so that the downward pressure will rapidly diminish, and the upward pressure increase. When the revolution has advanced sixty degrees from the position first considered, or when the crank of A is one hundred and fifty degrees from the vertical, the two pressures will balance; and when the piston A reaches its lower limit, the piston B being then at the middle of its course, the inferior body of air will occupy half its normal space in the lower half of the cylinder B, while the superior mass will fill the entire cylinder A, and half the cylinder B also. The upward pressure will now be two atmospheres, and the downward pressure less than two. During the preceding thirty degrees of revolution, therefore, the effective force of the engine will have been negative, and the same will continue to be the case until the crank A shall have passed forty-five degrees beyond its lowest point, or two hundred and twenty degrees from the vertical. The two cranks will then be equally inclined to the vertical on opposite sides of it, and their efforts to turn the shaft will be opposed to each other. These efforts being necessarily equal, and acting at equal distances from the centre of motion, will neutralize each other, and, for a moment, the effective force will be zero. When the piston B reaches the bottom, and the piston A is half advanced upward, the circumstances are the same mechanically as those with which the movement commenced, only now it is the inferior mass of air which is compressed into half its normal bulk in the hot cylinder, while the superior mass is dilated into once and a half the same bulk. It is further evident that this position is not that in which the difference of bulk of the two masses is absolutely the greatest, though it is here that the effective force is maximum; for, owing to the greater rapidity of movement of that piston which is nearest the middle of its course, it will be evident that, while the piston B is approaching the limit of the stroke, and the piston A receding from it, the volume of the inferior mass of air is, on the whole, enlarging, so that the point of minimum volume must occur before the completion

of the stroke of B. It actually occurs for the two bodies of air alternately, when the crank B is within thirty degrees of its culminations, upper or lower, and approaching them. This machine, if it could be realized, would possess two important advantages.

In the first place, its negative effect, or total active resistance, instead of consuming, as is usual in air-engines, two-thirds of the positive power, amounts to less than one-third. In the second place, it admits of increase of power without increase of dimensions, by the simple expedient of condensing the air within the cylinder in advance. In this case, indeed, some leakage might occur; but compensation for such a leakage could be provided without a great expenditure of force. In the third place, it gives, theoretically, the largest amount of work for the heat expended that it is practicable under any form to attain. But all these advantages are dependent for their realization upon the efficiency of the heating apparatus and the satisfactory performance of the regenerators. It encounters here the same difficulties which have impeded as yet the complete success of every form of hot-air engine.

II.—INFLAMMABLE GAS-ENGINES.

The enormous force developed in the explosion of gunpowder could hardly fail early to occupy the minds of the ingenious, with the effort to make it available for the uses of industry. Accordingly, we find that this problem formed a subject of study with such men as d'Hautfeuille, Huyghens, and Papin. But the intense energy of the force and the suddenness of its action seem to have discouraged the attempt to apply it directly as a motive power. The earlier experimenters occupied themselves with the endeavor to turn it to account by indirect means. The expedient which appeared to them most promising was to use it for the purpose of creating a vacuum. In fact, if a comparatively small charge of gunpowder be exploded in a closed vessel furnished with valves freely opening outward, the enormous expansion of the gaseous products of the explosion, an expansion due to the excessive heat developed, will drive out the atmospheric air through the valves, while the gases, contracting almost as suddenly as they expanded, will leave the vessel nearly void. It was first proposed to apply this principle to the elevation of water. A very simple apparatus suffices for this purpose. Let there be placed, for instance, such a vessel as has just been supposed, some fifteen or twenty feet above the level of a reservoir; a tube, open at both ends, communicating between this vessel and the reservoir will be all that is needed. So soon as the air has been expelled from the vessel by whatever means, the water of the reservoir will rise under the pressure of the atmosphere and occupy its place. This water may then be discharged at the superior level, and the apparatus will be ready for the repetition of the operation. In order to prevent the return of the water to the reservoir, when the orifices of discharge of the upper vessel are opened, the tube may have valves in it opening upward but closing under a downward pressure, or, what is simpler, it may be recurved at the upper

extremity and enter the explosion chamber by the top. Such was the application of this power suggested by d'Hautfeuille. Huyghens perceived that it was capable of being turned to more varied uses. He proposed to employ a cylinder with a movable but air-tight piston to serve as an explosion chamber, with a view to obtain a reciprocating motion. In fact, by blowing out the air contained in such a cylinder through valves properly disposed, the atmospheric pressure could be made to force the piston downward, and thus indirectly to move the arm of a lever to raise a weight or to turn a crank. The valves suggested and perhaps actually used by Huyghens for this purpose were sufficiently rude. They were nothing more than open but flexible leather tubes, which, after allowing the air to escape, were expected to collapse under the pressure from without, and prevent it from re-entering. Papin substituted for these a much more efficient and neater contrivance. This was to make an opening in the middle of the piston sufficiently large for the free escape of the air, and to cover this with a bell. The bell, yielding to the upward pressure, permitted the air to pass out, but, dropping immediately after into its place, effectually prevented its return. But none of these expedients sufficed to make a practically useful gunpowder engine.

In 1791, John Barber, a British inventor, patented a project for a new motive power, which may perhaps be regarded as embracing the germ idea of the modern imflammable-gas engine. This project, however, for it amounted to no more, was of the crudest sort. The motive force was to be derived from the direct action of a powerful current of flame, which he proposed to create by the combustion of inflammable gas mingled in explosive proportions with common air. The gas was to be generated by the destructive distillation of any combustible substances in a tight vessel. From the generator it was to be conducted into another chamber, called the "explosion chamber," common air being simultaneously introduced into the same vessel by a different channel. Under such circumstances combustion would of course be explosive, generating a powerfully outrushing stream of flame, which might be maintained as long as the gas should continue to be supplied. As the plan was to employ only the "*vis viva*" of this stream to turn a wheel or a windmill, the unpractical nature of the scheme needs not to be pointed out.

In 1794, another British inventor, by name Robert Street, patented a gas engine, founded on principles somewhat more rational than those which seem to have guided Barber, inasmuch as he clearly enough perceived that if heated gas is to be made the medium of applying mechanical power, it is through its elasticity, and not through the momentum of its mass, that we must expect to see the useful effect produced. But inasmuch as Street proposed to make the cylinder of the engine itself the generator of the gas by which the engine was to be driven, his scheme in a practical point of view was not a whit less visionary than that of Barber.

These early and, as they seem to us now, absurd projects, though they bore no fruit, and were probably never even subjected to a serious experi-

mental test, deserve mention in the history of this subject, as marking the progress of an idea destined at length to be successfully wrought out. Indeed, considered as an idea merely, it was successfully wrought out only a few years later. The gas engine, in every essential particular, such as it is at the present time, that is to say, actually realized in a form available for purposes of industry, was invented as early as 1799, and patented in France by an ingenious artisan named Lebon. Nevertheless, this machine was not a success. It attracted no notice in the scientific world, and inspired no confidence in the industrial. After the lapse of about half a century it was reinvented, and reinvented, doubtless, quite independently; the resemblance of the modern machine to that of Lebon being so complete that a description of one of them might easily be supposed to have been taken from the other. At the date of Lebon's invention illuminating gas had not yet come into general public use, but the mode in which he proposed to prepare the gas for his engine was precisely that which is now in universal use in the works of the great city gas companies. Having thus provided himself with a sufficient reservoir of this essential material, his plan was to introduce a certain charge of this into the cylinder of his engine beneath the piston, and simultaneously through another channel to admit a proper proportion of atmospheric air. The mixed gases were then to be exploded by means of the electric spark, their consequent dilatation furnishing the desired motive power. The inventor seems to have overlooked no provision necessary to secure the perfect success of his plan. The engine was entirely self-regulating. It operated two pumps, one of them designed to introduce the supply of gas, and the other that of air. According to the descriptions, by which only we know it, it would seem to have combined every feature important to secure success, and yet, as already stated, it was not successful. Its failure is probably to be attributed to the influence of several causes, which, in the progress of improvement in the industrial arts, and the simultaneous advancement of experimental science, have since ceased to exist. In the first place, as just remarked, inflammable gas had not yet been introduced for purposes of general illumination; and the preparation of gas for the engine must have been troublesome and disproportionably expensive. Electrical science, moreover, had not then reached such a state of perfection as to be in condition to suggest an apparatus for producing the spark required to inflame the gases, capable of operating with the unvarying certainty indispensable in such a machine; and finally, the mechanic arts were probably yet unequal to the requisitions of a problem involving the peculiar difficulties which the construction of this engine presented. In point of fact it can hardly be doubted that mechanical difficulties were among the principal obstacles which prevented the full realization of a project which, abstractly considered, seems to have been entirely feasible. Many other inventors since Lebon, have occupied themselves with gas engines. Until within the past ten years, none have succeeded in establishing their inventions in the confidence of the indus-

trial world. Of machines of this class which have left no trace except in history, it is unnecessary here to speak with minute detail. There is one of them, however, which deserves a passing mention, as having been distinguished from the rest by a feature which may be characterized as more bold than practical. This consisted in the proposed substitution of oxygen gas instead of atmospheric air in forming the explosive mixture by which the piston was to be driven, and hydrogen instead of coal-gas; the proportion being that required to form water by combination; so that after explosion the vacuum of the cylinder might be complete. It is true that immediately after the explosion, the water of combination would exist in the state of vapor, and that this would have a momentary elasticity so great as, by its direct action, to drive the piston to the end of the cylinder. But this vapor would be almost instantaneously condensed, especially if the cylinder were kept properly cooled; and a vacuum being thus formed practically perfect, the piston, on the opening of the valves for the admission of a new charge of gas to the opposite side, would be urged by the full pressure of the atmosphere upon its entire surface. If this idea could be practically realized, it would certainly be attended with very sensible advantage. In the gas-engine as now constructed, there is necessarily a period during each stroke in which the effective force is zero. This is the case during a great part of the time of admission of each successive charge of gas, which continues for one-half the length of the stroke. If during all this time there should be a vacuum in the opposite end of the cylinder, the engine, instead of being powerless, would be actuated by a positive working force upon the piston equal to one atmosphere; an advantage which more than doubles the efficiency as yet secured in any motor of this class. The project here described was patented by James Johnson, a British inventor, in 1841.

Mr. Tresca, in an interesting article published in the Annals of the Conservatoire, has expressed surprise that subsequent inventors have not occupied themselves more with this idea of Johnson. But in point of fact, the plan is much more plausible than feasible. To say nothing of the trouble and expense of generating the gases, which in the case of oxygen, especially, would be sufficient to defeat the economical object, the violence of detonation of the pure gases in the proportions suggested would be such as to endanger the safety of the machine, or to render the power unmanageable. It is also perhaps questionable whether, in practice, the condensation could be determined so as to take place at the moment desired. If the piston were free to take on the velocity of a projectile discharged from a gun, no doubt the pressure would follow it to the end; but if, owing to the connections by which the force is to be utilized, the motion of the piston is comparatively slow, the collapse may occur before it reaches the limit of its course. In such a case, the vacuum would be injurious. In order to reduce the violence of the explosion, the quantity of gas employed in each charge might be diminished, and the charge might be allowed to dilate to some extent, as it

would naturally do in consequence of the movement of the piston, before being fired. But these expedients would reduce correspondingly both the direct effect of the gas, and the indirect effect of the vacuum which it is sought to utilize. It is not very surprising, therefore, considering all the difficulties in the way, that no successful gas-engine has yet been constructed, deriving its power from the explosion of hydrogen with oxygen.

Three engines present themselves in the present Exposition which derive their force from the combustion of inflammable gas. Two of these employ the direct pressure of the gases as dilated by combustion. The third reverts to the principle which chiefly occupied the earlier inventors, viz: that of using the gases only as a means of clearing the cylinder of air, and rendering available the pressure of the atmosphere. It is to this last, which, though not earliest in the order of invention, revives the idea which belongs to the earlier period of this history, that attention will be first directed. This prominence of position may also be considered as due to this machine, since it was rewarded by the jury with a gold medal, while the other two just mentioned received a less honorable distinction.

OTTO & LANGEN'S GAS-ENGINE.

This machine is a Prussian invention, exposed by Messrs. Langen & Otto, of Cologne. Externally, it presents the appearance of a doric column something more than a metre in height, upon the enlarged capital of which is fixed a horizontal plate, which supports the arbor of the fly-wheel and other parts of the machinery. This column is the working cylinder. The mixed gases—common coal gas and air—are introduced at its base, and fired by an ingenious mode of communication with a gas jet, which is constantly burning. The base is surrounded by a jacket, between which and the cylinder itself cold water is always circulating, to prevent too great elevation of temperature. By the explosion of the gas, the piston, which has some weight, is driven to the top of the cylinder. The collapse which immediately follows produces a vacuum, or an approach to a vacuum, beneath the piston; and this now descends, urged by the pressure of the atmosphere with its own weight superadded. In order to transfer this force to the working arbor of the machine, the piston-rod is, on one side, provided with a rack, which acts on a spur wheel on the arbor. This wheel is loose upon the arbor, but is free to turn in one direction only; that is, in the direction which corresponds to the rising of the piston. In the descent, a ratchet and catch prevent its turning except as it turns the arbor with it. There are two tall uprights, one on each side of the piston-rod, which serve as its guides, and give stability to the machine. A second gear-wheel on the working arbor turns a similar wheel on another axis which carries the eccentrics by which the valves are governed. These eccentrics run loose on their shafts; but at a point of the descent of the piston when the piston itself is near the bottom of the cylinder, a cam on the rod causes them

to be fixed for a single turn, during which the charge of air and gas is admitted.

Figs. 1 and 2 in Plate III represent the parts of this machine which are essential to the understanding of its mechanism and mode of operation. Fig. 1 is a section through the axis of the cylinder taken parallel to the plane of the fly-wheel, and a projection in outline of the other parts. A is the cylinder and B the piston represented at the lowest point. The piston rod with its rack is distinctly shown. This rack gears into Z, the smaller of two spur wheels on the same axis, W, which is the axis, also, of the working arbor. The larger of these two spur wheels gears into an equal wheel to the left. Since this larger wheel is keyed on to the main shaft it turns constantly in the same direction as the fly-wheel, and it keeps, of course, the wheel into which it gears in uniform motion also. But on the axis of this wheel there are two eccentrics, *x* and *y*, which, running loose on the arbor, are usually motionless. But just as the piston reaches its lowest point, which is the position shown in Fig. 1, these eccentrics are seized and carried round for a single revolution, in consequence of the dropping of a catch, shown at *x*, into the ratchet wheel *t*, which is keyed to the arbor. In Fig. 2 this catch is shown in its usual position of detent, it being held free of the ratchet wheel by a projection on the lever *h*. When the piston reaches its lowest point the end of this lever *h* is acted on by a shoulder in the piston rod, as is seen at *n*, Fig. 1, and the catch is released. Falling into the ratchet *t*, it is dragged, and with it the eccentrics, in the direction of revolution; but at its first return to the position shown in the figure, it is caught again by the projection on the lever *h*, (which has now returned to its place,) and brought to rest. The manner in which these effects are produced may be thus explained. There are two eccentrics on the arbor which are firmly connected together, but which are set at about 90° from each other. One of them acts on a lever marked *m*, (seen in both figures.) Its office is to lift the piston from the lowest point through the space required for the admission of the new charge of gas. That of the second is to act on the slide valve shown at *s*. This slider in the figure is in the position which it assumes to admit of the expulsion of the products of combustion after each explosion. On the descent of B the valve *p* opens outward and the gases escape. The opening for the admission of the fresh charge is not in the same vertical plane as that for the exhaust, and hence it does not appear in this section.

So soon as the piston has reached its lowest point, and, acting on the lever *h* through the shoulder *n*, has released the catch *x*, one of the eccentrics acting upon the lever *m* immediately raises the piston through a space large enough for the aspiration of the new charge. It is, of course, necessary that a special provision should be made for this first movement of the piston, which is at this moment entirely detached from the machine. The lifting of the piston, of course, releases the lever *h*; and this occurs within the first quarter of a revolution, so that the

eccentrics are necessarily caught when the revolution is complete, while at the same time the slide valve is brought into position to cut off further admission of gas, and to introduce a flame from a small fixed burner for the purpose of firing the charge.

By the explosion the piston is driven to the top of the cylinder, the gear wheel Z running loose on the arbor as it rises; but on its descent immediately after, under the pressure of the atmosphere, this wheel is prevented from turning by the catches *k r*, except as it carries the arbor with it. As the elasticity of the gases within the cylinder falls almost immediately nearly to zero, the effective pressure exerted on the piston is almost an atmosphere.

In Fig. 1, (Plate III,) both the levers *h* and *m* are shown at their lowest point. In Fig. 2, (Plate III,) *h* is at its highest point and *m* at its lowest, the piston being now near the top of the cylinder. When, in the revolution of the eccentrics, *m* is also at its highest point, it is higher than the position of *h* as shown in either figure.

In regard to the performance of this machine, as it respects the quantity of the combustible consumed and the amount of force developed, information was repeatedly sought; but nothing could be ascertained on the subject from the exhibitor, beyond the general statement that the consumption of gas per horse-power per hour is in round numbers thirty cubic feet. No details were supplied in regard to the experimental trials by which this determination was arrived at.[1] Assuming it to be correct, this engine may be said to work economically; though less so than the steam-engine. Thirty cubic feet of gas, with gas at twenty-five cents per one hundred cubic feet, would amount to seven and a half cents; while six pounds of coal, which in a steam-engine would do the same work, costs less than two cents, coal being estimated at $6 per ton. In Paris gas costs but seventeen cents per hundred cubic feet, and coal is higher. On the other hand it is in favor of the gas-engine that it requires no expense of fuel to prepare for work, and that the expenditure ceases at the moment the engine is stopped. There is not only in this respect an economy of expense, but an economy also of time and of the labor of

[1] The desired information on this point was obtained at a later period from the results of experiments made before the jury of class 53, which have been published by Professor Karl Jenny, of Vienna, a member of the jury. The consumption of gas for the driving of the engine, and that employed for maintaining the burner employed to fire the charges, were separately measured. The power developed was determined by means of a Prony dynamometer. Four experiments were made, each continuing for half an hour, with the exception of the last, which was extended to thirty-four minutes. The power developed varied from 0.568 to 0.608-horse power; but in the mean of the four experiments was 0.582. The total consumption of gas amounted to 1.303 cubic metre, of which 0.165 cubic metre was consumed by the burner, and the remainder, 1.138 cubic metre, by the engine itself. Considering only this last, the consumption per horse-power per hour averaged 0.95 cubic metre, the best performance requiring but 0.900 cubic metre, and the worst 1.040 cubic metre. Taking into consideration the consumption of the burner, the average total consumption was 1.083 cubic metre. This is twofold the amount required according to the statement of the exhibitor. At the same time it must be remarked that the consumption of the burner, which, however, is but a small fraction of the whole, is the same for a large as for a small power.

attendance. And, moreover, the machine is perfectly safe, whether as regards liability to explosion or danger of fire. Insurance companies, therefore, exact no premium for its installation. On the other hand, it must be said of this machine that it does its work by no means silently; and that, unless in a workshop already so noisy that a littiem ore or less of din is a matter of secondary moment, it must be a disagreeable companion. It need hardly be added, that the violence of its action during the first part of each pulsation is such as necessarily to limit its employment to low powers. The inventors offer machines at the following rates as delivered in Cologne:

Engine of $\frac{1}{2}$-horse power,	350 thalers	$130
Engine of 1-horse power,	450 thalers	170
Engine of 2-horse power,	580 thalers	220

LENOIR'S GAS-ENGINE.

The gas-engine of Mr. Lenoir, exposed in the French department, employs, like that which has just been described, a mixture of coal gas and common air as the source of its motive power; but it uses the direct force developed by the explosion of the mixture to produce motion, precisely as the pressure of steam is employed in an ordinary steam-engine. This machine was patented in 1860, and is now very extensively in use. Paris has one hundred and fifty of these engines in operation, and there are at least an equal number at work in the provinces of France and in foreign countries. England has seven or eight, and Russia as many. Some few have found their way to Cuba, Peru, and Chili. It is evident, therefore, that this machine has achieved a practical success.

The essential parts of this engine are a horizontal cylinder, with a piston which communicates motion by means of a crank to an arbor which carries a fly-wheel, and through which the power is to be applied to use. The fly-wheel is made very heavy for a double reason. First, there is no driving power during one-half of each stroke, and a large reserve of accumulated force is necessary to continue the work of the engine and to overcome the passive resistances during this period; and secondly, the explosive energy of the gases is great, but is only of very brief duration. The inertia of a large wheel is therefore necessary to maintain the uniformity of movement necessary to useful work.

Plate III, Fig. 3, represents the elevation of a machine of one-horse power, on a scale one to ten. It will be seen to resemble a steam-engine in all its essential parts; and, as in that engine, it has valves governed by an eccentric on the main shaft. The cross-section, Fig. 6, shows that the cylinder is surrounded by a jacket. Between this and the cylinder itself cold water circulates, to prevent excessive elevation of temperature. Figs. 5 and 5*a* show the construction of the slide-valves, and their relation to the cylinder is shown in Fig. 6. The cylindrical vessels E and E′ are the valve-boxes. The gas enters E by the tube *e*. It passes through the orifices *d′* (Fig. 5) into the cylinder by corresponding orifices. Air enters at the same time through the free space between the

two faces of the slider, (Fig. 5*a*,) which space, as the same figure shows, communicates with the small gas-passage d'. The air and gas therefore mingle progressively as they enter the cylinder; when the piston reaches the middle of its course, the slider cuts off further supply, and an electric spark from a Ruhmkorff coil fires the mixture in the cylinder, and the piston is impelled with great force toward the end of the cylinder which it is already approaching by the effect of the inertia of the fly-wheel.

It is easy to imagine many modes in which the rupture of an electric circuit may be periodically determined by the motion of a machine. The mode employed in this instance is illustrated in Fig. 7. A and B represent two elements of a Bunsen battery. A Ruhmkorff coil is enclosed within the case represented at E. The current from A B is carried to f through the interruptor f'. It traverses the principal circuit of the coil in E, and then, through the wire h p, passes to the inner ring of a circuit breaker, represented in H. This ring is metallic and is insulated. Externally to it are the metallic arcs p r, which are also insulated from the inner ring. The two rings are concentric with the axis of the main shaft of the engine, and this shaft carries at its extremity an insulated metallic arm K, which is always in contact with the inner ring, and which makes and breaks contact with the outer arc, as the shaft turns. The arcs p and r are connected by wires attached at a and b, which unite at n with the other pole of the battery. A wire from e to m connects the end of the secondary coil with the metal of the gas-admission tube T. Another insulated wire d connects the other end of the same coil with the binding screws d' and d'', which communicate with the interior of the cylinder by two insulated metallic points. Fig. 4, K shows the arrangement of these points. Their place in the machine is shown in Fig. 3, at K and K′.

As the principal circuit is broken from time to time at H, a spark passes from one or the other of the insulated points, at d' or d'', to the metal of the cylinder, firing the explosive gases, if there be any present. It is of course easy to adjust the circuit breaker H, by turning it on its centre, so as to produce the spark at any moment of the revolution which may be desired.

No-air pumps are used with this engine. The inspiration of the gases is effected by the movement of the working piston itself. The inflammable gas is most advantageously taken from a gasometer; but it may be taken directly from the tubes supplying the illumination to the building, provided there be interposed an elastic bag large enough to hold several charges. This contrivance is represented in the last diagram, where g is a bag of caoutchouc placed just before the point of admission of the gas to the engine. In this bag the gas should be under some tension. In the action of the machine, it swells and collapses in a manner resembling the action of the lungs.

The proportions in which the air and gas are mingled is one part of gas to thirteen and a half of air. Originally the proportion of gas

employed was as one to nine, but practice has shown it to be more advantageous to employ a greater degree of dilution.

Instead of the Bunsen battery the simpler sulphate of copper battery of Daniell is now generally used. When once arranged, it maintains its action for long periods with very little attention.

The water required for the refrigeration of the cylinder may, in some localities, require to be made the subject of a special provision. Where there are public water-works supplying an abundance for all purposes, there will be no difficulty; but under other circumstances it is necessary that the circulation be maintained by a small pump worked by the engine. The water, however, if kept in a large reservoir exposed to the weather, will cool fast enough to be used repeatedly, provided the reservoir have a capacity proportioned to the power of the engine, and provided also that the supply water be drawn always from the bottom of the reservoir, while the escape water is discharged at the top.

For a half-horse power engine the reservoir should have a capacity of 500 litres, say 130 gallons; for one-horse power, 1,200 litres, say 320 gallons; for two-horse power, 2,000 litres, say 530 gallons; for three-horse power, 3,000 litres, say 800 gallons.

The Lenoir engine has been made the subject of repeated experiments by Mr. Tresca, and from his published results we obtain the most exact information in regard to its capabilities that could be desired. In the first place, the pressure, which is of course at its maximum immediately after the explosion, is shown by the manometer to diminish with singular rapidity; so that if the stroke were not quite short as compared with that which is usual with a steam piston of similar diameter, the effect would inevitably become negative before its completion. It appears also that, with the proportions in the mixture above named, the maximum pressure hardly reaches six atmospheres, a pressure not considered excessive with steam; but it affects the indicator with a much more sudden start than does steam of the same pressure.

Mr. Tresca's first observations were made upon a machine of a little over one-half of one-horse power. The consumption per horse-power per hour was inferred to amount to something more than three cubic metres, or over 100 cubic feet of gas per horse-power per hour. With gas at twenty-five cents per 100 cubic feet, this would make the power sufficiently expensive—too much so, in fact—to compete with steam in cases where steam could possibly be employed. But as a substitute for the labor of men, in turning a windlass, for instance, or in driving a lathe, or a printing press, and for many similar kinds of work, it may be practically economical. And for intermittent labor, it is a very important consideration that the consumption does not go on while the machine is at rest.

Mr. Tresca subsequently experimented on another of Mr. Lenoir's engines, having nearly double the power of the first, or nine-tenths of one-horse power. In this case the result was more favorable, the consumption being reduced to 2.7 cubic metres per horse-power per hour. It is not sur

prising that such a difference should have been found, since small engines of all kinds are subject to a more than proportional amount of loss in overcoming passive resistances; and in the present case it may be said that the cooling of a small mass of hot gas confined within metal walls will be much more rapid than that of a larger body. We may therefore reasonably conclude that a Lenoir engine of two-horse power would not consume more than two and a half cubic metres per horse-power per hour.

The prices at which these engines are furnished in Paris are as follows:

Engine of ½-horse power, without governor...1,100 francs = $220.
Engine of 1-horse power, without governor...1,600 francs = $320.
Engine of 2-horse power, with governor......2,500 francs = $500.
Engine of 3-horse power, with governor......3,000 francs = $600.

HUGON'S GAS-ENGINE.

The third gas-engine exposed is that of Mr. Hugon. It resembles in many respects the engine just described, but presents two or three points of difference of some importance. The first concerns the manner of inflaming the gas. Mr. Hugon, like Mr. Lenoir, first employed the electric spark for this purpose; but, finding that inflammation sometimes failed to occur, whether from the failure of the spark or from the imperfect mixture of the gases, he abandoned that plan and adopted a more infallible expedient. This may be understood by referring to Figs. 3, 4, and 5, which follow:

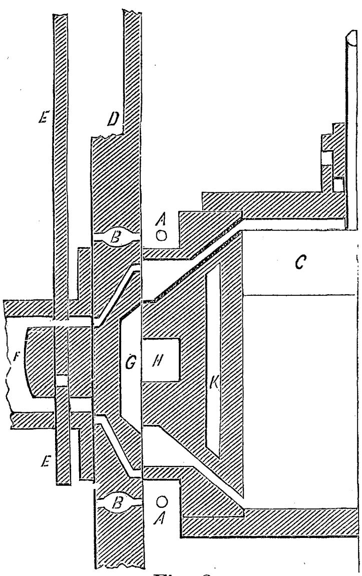


Fig. 3.

These figures represent, in section, the cylinder, with the slide-valves designed for the distribution and inflammation of the gases. All the figures are similarly lettered, and represent different successive positions of the movable parts. These parts are distinguished by the letters EE and DD. The first is designed for the distribution, and the second for the inflammation of the gases. The gases are admitted from the space F, which is the end of a large pipe in which they are mingled. In Fig. 3, the slide E is in the position which opens communication with the part of the cylinder behind the piston C. The other slide D is in a corresponding position, and it will be seen that the passage is free from F to the upper part of the cylinder, while between F and the lower part of the cylinder communication is doubly cut off. But in this position of D the lower part of the cylinder communicates through G with H, which is the eduction pipe for the exhaust gases.

As the piston advances, the mixed gases continue to flow in from F until a sufficient supply has entered the cylinder, when the slide E takes the position shown in Fig. 4, and communication with the reservoir is closed. At the same time the slide D advances to the successive positions shown in Figs. 4 and 5. This slide carries, in two little recesses marked B, two gas jets, of which the office is to fire the charges in the upper and lower parts of the cylinder successively. In Fig. 5 it will be seen that there is an opening by which the upper jet B is in communication with the explosive mixture above the piston. In this manner the mixture is fired. But, as the effect of the explosion is to exhaust the oxygen in the cylinder, the jet B is necessarily extinguished. A provision is therefore necessary to insure its being

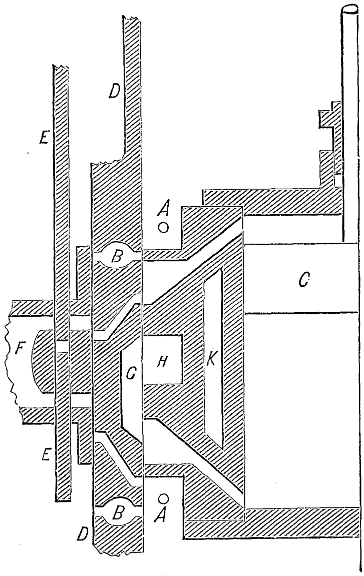


Fig. 4.

rekindled before its service is again required. In order to accomplish this object, a permanent light is placed at A, outside of the cylinder. In Fig. 3 the movable jet B is represented just opposite to A, and in this position it is lighted by communication through the free opening on that side. In Fig. 4 the lower jet is in position to be lighted by another permanent light, marked A also.

When the piston reaches the end of its course the slide D is drawn upward so far as to open a free communication between F and the lower chamber of the cylinder. A new charge enters on that side; and this is fired by the lower movable jet B. Thus the operation goes on indefinitely.

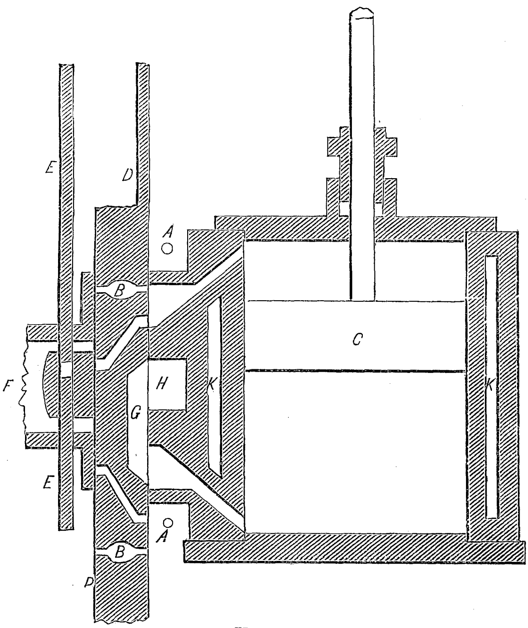


Fig. 5.

The space K, which is shown in all these figures, is the interval between the cylinder and its jacket, in which cold water is kept constantly circulating. This is a provision necessary in every gas engine to prevent excessive elevation of temperature. Another expedient which contributes to the same end is the introduction into the interior of the cylinder itself of a small quantity of water along with every charge of gas. A double advantage results from this. By its evaporation the water absorbs some heat, and in becoming steam at the same time it prevents the abrupt fall of pressure which follows the explosion when the gases are admitted entirely dry. The reality of the advantage is made very apparent by the curves traced by the index of the manometer, or pressure gauge, when the water is present and when it is absent. In the two figures which follow, the first, Fig. 6, shows the violent oscillations, and the abrupt rise and fall of pressure, which are occasioned by the explosion of the gases in the absence of water. The second, Fig. 7, exhibits the evidence of the much better sustained pressure produced by the steam.

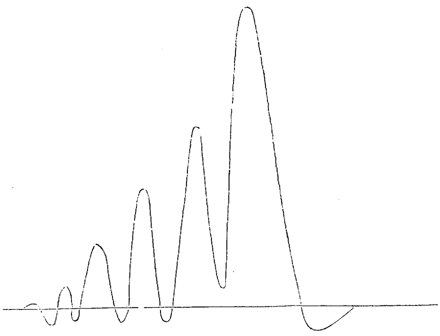


Fig. 6.

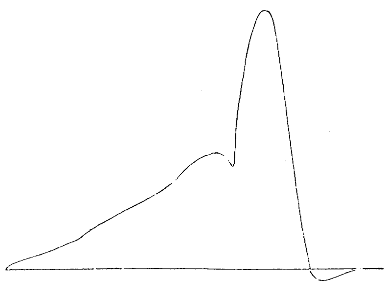


Fig. 7.

In both these figures, it will be seen that the curve descends, on the right, for a short distance below the horizontal line. This marks the period of admission of the gases to the cylinder when the pressure is negative.

The introduction of water into the cylinder, as here explained, constitutes the second peculiarity in which the present engine differs from that of Mr. Lenoir. The other differences are of minor importance. Mr. Hugon's engine employs a kind of bellows worked by the engine for the introduction of the gas into the space where it is mixed with air, and he effects this mixture before the charge is introduced into the cylinder. Mr. Lenoir draws both the gas and the air directly into the cylinder by the motion of the working piston itself, and relies for their mingling upon the arrangement of the admission tubes.

In the particulars of its construction this engine differs considerably from that last described. Figs. 8 and 9, Plate III, illustrate this construction. The first is a vertical section through the axis of the cylinder and of the working shaft.

The cylinder is shown at A, the small space *a* being the interval between it and the jacket, which is filled with cold water.

B is the piston with its rod *b*, guided by the support *b'*.

C is the connecting rod, which is forked below, and attached above to the crank.

D is the arbor moved by the crank, and carrying the pulley *d*, by which the motive power is applied. The same arbor carries the fly-wheel V at the extremity.

E is the slide carrying the portable gas jets K K, and serving also to open the escape passage to the exhaust gases.

F is the induction slide, admitting the explosive mixture to the cylinder.

G is the compressor by which the inflammable gas is introduced into the chamber where the mixture is formed.

I is the reservoir of inflammable gas.

J J are the fixed gas jets, and K K the movable. The second figure is an elevation of the machine seen laterally.

Experiments made upon this machine, at the *Conservatoire des Arts et Métiers*, show that its consumption amounts to 2.6 metres cube per horse-power per hour. In this is included the amount, which is considerable, consumed by the jets employed to inflame the charges. It appears also that, as in the case of the Lenoir engine, the maximum pressure is between five and six atmospheres, and the mean (effective) pressure throughout the stroke less than half an atmosphere.

The introduction of water into the cylinder of this machine is an important feature of its operation, contributing to its efficiency by giving greater permanence to the elastic force of the products of the explosion, the steam derived from this water being one of these. It would seem probable that, by carrying out this idea further than it is here done, results might be attained still more favorable. An engine operating upon this principle was constructed some years ago, in London, by Messrs. W. and C. F. Siemens, and was exhibited at the Exposition of 1862; but it has not been brought forward again in that of 1867. In the engine of the Messrs. Siemens the object aimed at was to generate as much steam as the heat furnished by the combustion of the inflammable gas would allow; and a regenerator was employed to receive the heat of the exhaust gases for the purpose of transferring it to the entering charge. Though no exact statements of the economy realized in the working of the engine of the Messrs. Siemens appear to have been published, it would seem, in theory, to be preferable to either of those which have here been described, both as it regards the mode of action of the power and the cost of maintenance.

It might be said that an engine which, while nominally a gas-engine, owes thus its principal merit to the steam which it generates, is, in fact, only a steam-engine in disguise, and might, therefore, better be replaced by the steam-engine in its ordinary form. To this it may be replied that there is a very essential difference between the present engine and the

ordinary steam-engine, which consists in the fact that this has no boiler, and that it generates the steam which it uses in the cylinder itself. This is a very important advantage. The dangers of explosion are removed entirely. The machine is always ready for work. The expense ceases the moment the work is over; and the work may be interrupted and resumed any number of times during the day, without involving any waste of fuel during the intervals of repose. To this it may be added that gas-engines create no dust or ashes, and require no labor to be expended in the transportation of fuel or the removal of cinders. Moreover their use is attended with no danger of fire to the buildings or the apartments in which they operate; and they can, on this account, be introduced in localities from which steam-engines would be necessarily excluded. And finally, though in point of economy they may not compete with steam, yet they may often furnish a convenient power much cheaper than the human labor, which they will, in many cases, be employed to replace.

It is one important disadvantage attendant on these engines, that, in situations where illuminating gas is not manufactured on the large scale for public use, they are unavailable without a special apparatus for generating the gas. The engine of Mr. Siemens is accompanied by such an apparatus; but the additional trouble which its use occasions cannot but be objectionable. It is worthy of consideration whether some of the cheap and very volatile hydrocarbons, all of which furnish a vapor which is explosible in mixture with common air, might not be advantageously employed to replace coal gas. Supposing this to be successfully accomplished, the use of the class of motors under consideration might be very largely extended.

III.—AMMONIACAL GAS-ENGINES.

If hot-air engines and inflammable gas-engines fail as yet to furnish power comparable to that which steam affords, without a very disproportionate increase of bulk, and for high powers fail to furnish it at all, the same objection will not hold in regard to the new motors now beginning to make their appearance, in which the motive power is derived from ammoniacal gas. This gas, which is an incidental and abundant product in certain manufactures, especially that of coal gas, and which makes its appearance in the destructive distillation of all animal substances, is found in commerce chiefly in the form of the aqueous solution. It is the most soluble in water of all known gases, being absorbed, at the temperature of freezing, to the extent of more than a thousand volumes of gas to one of water; and at the temperature of 50° F, of more than eight hundred to one. What is most remarkable in regard to this property is, that, at low temperatures, the solution is sensibly instantaneous. This may be strikingly illustrated by transferring a bell-glass filled with the gas to a vessel containing water, and managing the transfer so that the water may not come into contact with the gas until after the

mouth of the bell is fully submerged. The water will enter the bell with a violent rush, precisely as into a vacuum, and if the gas be quite free from mixture with any other gas insoluble in water, the bell will inevitably be broken. The presence of a bubble of air may break the force of the shock and save the bell.

This gas cannot, of course, be collected over water. In the experiment just described, the bell is filled by means of a pneumatic trough containing mercury. It is transferred by passing beneath it a shallow vessel, which takes up not only the bell-glass but also a sufficient quantity of mercury to keep the gas imprisoned until the arrangements for the experiment are completed.

The extreme solubility of ammoniacal gas is, therefore, a property of which advantage may be taken for creating a vacuum, exactly as the same object is accomplished by the condensation of steam. As, on the other hand, the pressure which it is capable of exerting at given temperatures is much higher than that which steam affords at the same temperatures; and as, conversely, this gas requires a temperature considerably lower to produce a given pressure than is required by steam, it seems to possess a combination of properties favorable to the production of an economical motive power.

Ammonia, like several other of the gases called permanent, may be liquified by cold and pressure. At a temperature of —38°.5 C, it becomes liquid at the pressure of the atmosphere. At the boiling point of water it requires more than sixty-one atmospheres of pressure to reduce it to liquefaction. The same effect is produced at the freezing point of water by a pressure of five atmospheres, at 21° C (70° F) by a pressure of nine, and at 38° C (100° F) by a pressure of fourteen.

If a refrigerator could be created having a constant temperature of 0° C, or lower, liquid ammonia would furnish a motive power of great energy, without the use of any artificial heat. The heat necessary to its evaporation might be supplied by placing the vessel containing it in a water-bath, fed, at least during summer, from any natural stream. Such a condenser could not be economically maintained. A condenser at 21° C, however, and an artificial temperature in the boiler of 38° C, would furnish a differential pressure of five atmospheres, with a maximum pressure of fourteen. By carrying the heat as high as 50° C, (122° F,) a differential pressure of eleven atmospheres could be obtained, with an absolute pressure of twenty.

These pressures are too high to be desirable or safe. Moreover, condensation is more easily effected by solution than by simple refrigeration, and hence, in the ammoniacal gas engines thus far constructed, the motive power has been derived, not from the liquified gas, but from the aqueous solution. The gas is expelled from the solution by elevation of temperature. At 50° C (122° F) the pressure of the liberated gas is equal to that of the atmosphere. At 80° C (176° F) it amounts to five atmospheres, and at 100° C (212° F) to seven and a half. At lower temperatures the gas is re-dissolved, and the pressure correspondingly reduced.

In the ammoniacal engine, therefore, the expulsion and resolution of the gas take the place of vaporization and condensation of vapor in the steam-engine. The manner of operation of the two descriptions of machine is indeed so entirely similar, that but for the necessity of providing against the loss of the ammonia, they might be used interchangeably. The ammonia-engine can always be worked as a steam-engine, and the steam-engine can be driven by ammonia, provided the ammonia be permitted to escape after use. The advantage of the one over the other results from the lower temperature required in the case of ammonia to produce a given pressure, or from the higher pressure obtainable at a given temperature. These circumstances are favorable to the economical action of the machine in two ways. In the first place, they considerably diminish the great waste of heat which always takes place in the furnace of every engine driven by heat; the waste, that is, which occurs through the chimney without contributing in any manner to the operation of the machine. This waste will be necessarily greater in proportion as the fire is more strongly urged; and it will be necessary to urge the fire in proportion as the temperature is higher at which the boiler, or vessel containing the elastic medium which furnishes the power, has to be maintained. In the second place, that great loss of power to which the steam-engine is subject, in consequence of the high temperature at which the steam is discharged into the air, or into a condenser, is very materially diminished in the engine driven by ammoniacal gas.

For instance, steam formed at the temperature of 150° C (302° F) has a pressure of nearly five atmospheres (4.8.) If worked expansively, its pressure will fall to one atmosphere, and its temperature to 100° C (212° F) after an increase of volume as one to four. If, now, it is discharged into a condenser, there is an abrupt fall of temperature of 50°, 60°, or 70°, without any corresponding advantage. If it is discharged into the air, this heat is just as much thrown away. In point of fact, when steam of five atmospheres is discharged into the air at the pressure of one, considerably more than half the power which it is theoretically capable of exerting is lost; and when, at the same pressure, it is discharged into a condenser, more than one-quarter of the power is in like manner thrown away. And as the expansion given to steam is usually less than is here supposed, the loss habitually suffered is materially greater.

The ammoniacal solution affords a pressure of five atmospheres at 80° C, (176° F,) and in dilating to four times its bulk, if it were a perfectly dry gas, its temperature would fall below 0° C. But as some vapor of water necessarily accompanies it, this is condensed as the temperature falls and its latent heat is liberated. The water formed by condensation dissolves also a portion of the gas, and this solution produces additional heat. In this manner an extreme depression of temperature is prevented, but it is practicable, at the same time, to maintain a lower temperature in the condenser than exists in that of the steam-engine. It must be observed, however, that owing to the very low boiling-point of the solu-

tion it is not generally practicable to reduce the pressure in the condenser below half an atmosphere.

The advantages here attributed to ammoniacal gas belong also, more or less, to the vapors of many liquids more volatile than water; as, for instance, ether and chloroform. Engines have therefore been constructed in which these vapors have been employed to produce motion by being used alone, or in combination with steam. The economy of using the heat of exhaust steam in vaporizing the more volatile liquid is obvious. But all these vapors are highly inflammable, and in mixture with atmospheric air they are explosive. The dangers attendant on their use are therefore very great. Ammonia is neither inflammable nor explosive, and if, by the rupture of a tube or other accident, the solution should be lost, the engine will still operate with water alone.

The action of ammonia upon brass is injurious; but it preserves iron from corrosion indefinitely. It contributes, therefore, materially to the durability of boilers. A steam-engine may be converted into an ammonia-engine by replacing with iron or steel the parts constructed of brass, and by modifying to some extent the apparatus of condensation.

FROT'S AMMONIACAL GAS-ENGINE.

But one engine was exhibited in the Exposition operated by ammoniacal gas. This was one which had been originally constructed as a steam-engine for the imperial marine, and which has been placed at the disposal of the inventor, Mr. Frot, of Paris, by order of the Emperor. It is of fifteen-horse power. This machine has been made the subject of a series of experiments by a commission appointed by the ministry of marine, whose report upon its performance has not yet appeared. The inventor affirms, however, that its consumption of fuel per horse-power per hour is not more than one-third of that of a steam-engine working under similar conditions. The machine being itself a steam-engine, it has been possible to make comparative experiments with all desirable exactness, by using steam and ammonia alternately.

The modifications made in the condensing apparatus have been only such as are necessary to re-dissolve the gas to a degree of saturation sufficient to make it available for repeated use, and to return the solution to the boiler. For this purpose the condenser has two chambers instead of one. In the first the gas, with the steam which accompanies it, passes through a series of tubes surrounded by water, where the steam is condensed and the gas is to a certain extent cooled. From this it passes into a second, into which is at the same time injected a small quantity of water, which, along with the water from the condensed steam, completes the solution of the gas. This vessel is called the dissolver, and the name condenser is applied only to the one first mentioned. The dissolver is kept cool by means of a series of tubes passing through it, in which the water of refrigeration circulates. The water passes first through these tubes, and afterwards surrounds the tubes of the con-

denser. From the dissolver the saturated solution is withdrawn by a pump, which forces it into the boiler. But as the boiler would in this way be liable to become overcharged with liquid, while the strength of the solution would at the same time grow gradually weaker, care is taken to prevent these disadvantageous consequences by drawing from the boiler itself the water used for injection. In fact, as the gas is gradually expelled by heat from the solution in the boiler, and as the specific gravity of the solution is greater in proportion as its strength diminishes, it will happen that the lower strata will generally be reduced to the condition of pure water, or will contain only an insignificant amount of ammonia. This portion of the solution is gradually withdrawn in measure as the saturated solution is introduced at the top, and after passing through a refrigerator is employed for injection into the dissolver. As a further measure of economy, this water, on its way to the refrigerator, is made to impart a portion of its heat to the saturated solution returning to the boiler, by passing through a jacket surrounding the tube by which this solution returns.

With the exception of possible and trivial leakage, the same water and the same gas, therefore, keep up a perpetual circulation between the boiler and the dissolver, without increase or diminution. In regard to leaks every preventive precaution is taken. The pungent nature of the gas renders this a matter of no slight importance, apart from considerations of economy. There is, however, very little leakage, if any at all. It could only occur at the surfaces of contact of the movable parts, and as these are lubricated with oil, the alkali saponifies the lubricant and produces an unctuous compound which, while it answers all the purposes of lubrication, closes the joint effectually against the escape of gas.

Before commencing work it is necessary with this engine, as with the steam-engine, to clear all parts of the interior from atmospheric air. This is done, as with steam, by blowing through; but to prevent any loss of ammonia in the process, the air which is expelled is passed through water, where it leaves in solution any ammoniacal gas which may accompany it. The same vessel of water being constantly used for this purpose, there will gradually be formed a strong solution which may at length be employed to feed the boiler.

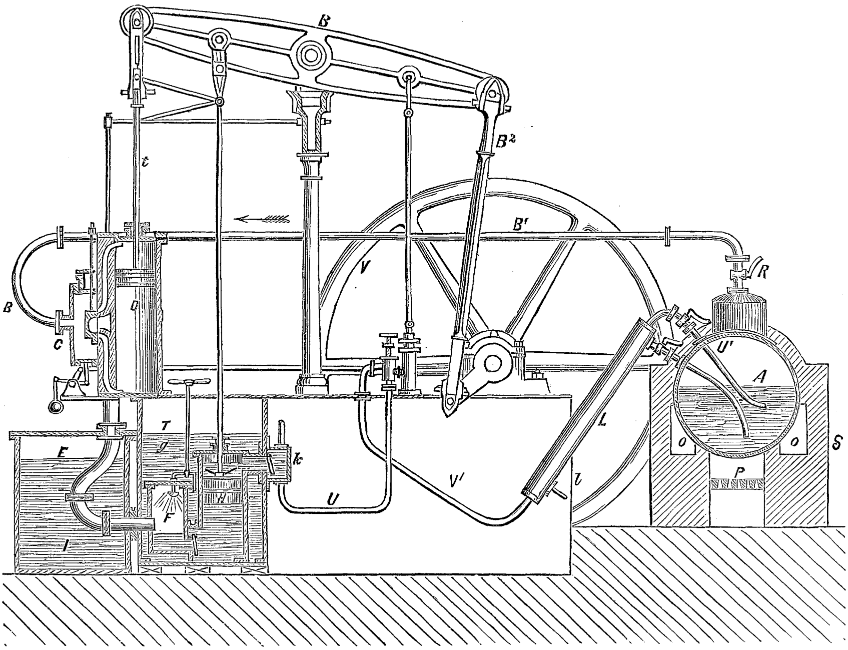
It is the statement of the inventor, that any steam-engine may be transformed into an ammonia engine at a cost not exceeding thirty dollars per horse-power. For machines of more than fifty-horse power, the proportional expense will be less. The inventor further states, that the cost of making the necessary changes will be largely reimbursed within the first year by the saving of combustible. Putting the expense per horse-power of the steam-engine for fuel at about a franc a day, or seventy-three dollars a year, the saving which he proposes to effect, which is two-thirds of the whole, will amount to forty-eight dollars per horse-power, exceeding by more than fifty per cent. the cost of the transformation of the engine.

Mr. Frot is not the only inventor who has occupied himself with this application of ammonia. In 1859 a patent was taken out in Paris, by an inventor named Delaporte, for an engine working upon the same principle as that which has just been described.

DELAPORTE'S AMMONIA-ENGINE.

Other patents have been taken out for similar machines in America, and perhaps in England, but it is not known how far they have been brought into use, if, indeed, they have been so as yet at all. Fig. 8 represents one of these machines, all of which necessarily resemble each other in substance, though they may differ in details.

Fig. 8.



Delaporte's Ammonia-engine.

A is the boiler, D the cylinder, and B the tube communicating between the cylinder and the boiler. C is the valve box and x the slider by means of which the gas is introduced alternately above and below the piston. E is the eduction pipe and F the condenser and dissolver. In this machine, the condenser and dissolver are not separate, as in Mr. Frot's. The water of injection is introduced by a pipe and rose jet at the top of the condenser F. The solution passes from F into H, from which it is withdrawn by the piston H, passing through the reservoir k and the tubes U and V′ by which it is returned to the boiler. As its return is opposed by the elasticity of the gas in the boiler, it must be forced in, and a small forcing pump, is employed for this purpose. The tube V′ is surrounded

by a jacket L. The water which has been deprived by heat of its ammonia is withdrawn from the bottom of the boiler by the lower tube, and passes into the jacket L, where it imparts a portion of its heat to the solution in the tube V′, which is on its way to the boiler. It is then discharged at l by a connection, not shown, and carried through a refrigerator, which is also not shown, after which it is conveyed into the vessel T, and is employed for injection into the dissolver F.

There seems to be little reason to doubt that the ammoniacal engine is, in fact, more economical in its operation than most forms of the steam-engine. But the principal theoretic ground on which inventors have usually endeavored to prove that it ought to be so is one which is by no means tenable. This ground is, that the latent heat taken up by ammonia when expelled from its aqueous solution is less than that of steam. As what we have denominated the economical coefficient of an engine driven by heat is entirely independent of any question concerning the latent heat of the elastic medium employed, such reasoning is altogether fallacious. But as this species of argument is continually presenting itself anew, not merely in the case of ammonia but in that of a variety of other gaseous or volatile substances, it may not be inappropriate to devote a few words to an examination of the fallacy. In point of fact theory is too frequently appealed to in the discussion of economical questions connected with this subject, by persons whose reasonings show them to be unacquainted with the fundamental truths of thermo-dynamics, and unaware that they are contradicting established principles of the science to which they appeal. Between two given machines driven by heat, and performing each the same amount of work in the same time, the question which, if either, is the more economical, is really more a practical than a theoretic question, and one which must be settled experimentally. Theory can only indicate a certain limit beyond which economy cannot be carried, and point out the conditions which favor the attainment of this limit. These are, large expansion, the suppression of losses by radiation, conduction, leakage, &c., and the employment of regenerators. But between two machines in which these conditions are equally observed, and in which the maximum and minimum temperatures are the same, theory furnishes no ground for supposing that there will be any economical difference. The question is not in the least affected by the substitution of one elastic medium for another, heated air, the vapor of ether or chloroform, or ammoniacal gas, for instance, instead of steam: while the limits of temperature are the same, the proportion of heat converted into work, and the proportion merely transferred from the furnace to the condenser without contributing anything to the work performed, will be the same for all. It is true that with the same *difference* between the upper and lower temperatures, there will be a theoretic advantage in favor of the machine in which the *absolute* temperatures are lowest, but practically the lower limit of temperature cannot be depressed below the temperature of the

natural waters which furnish the means of refrigeration; and this lower limit is equally available for all machines.

It cannot, in fact, be too much insisted on, that the largest prospect of improvement in regard to the economy of engines driven by heat is in the direction of the better application of the heat of the furnace. The principal loss is in that large amount of heat which merely passes through the flues of the chimney, without being absorbed by the elastic medium at all, and which is, of course, mere waste.

Many inventors of engines which employ substitutes for steam, and among them the inventor of the ammoniacal engine in the Exposition, insist very much on the difference between the *latent heats* of different vapors, as affecting the economy of the use of those media as sources of power. Latent heat is treated by them as a dead weight to be carried, as a simple charge upon the machine, to the efficiency of which it contributes in no manner whatever. And yet nothing can be more true, or more easily demonstrated, than that the proportion of heat converted into work by a machine working between two given limits of temperature, under the conditions required to secure the largest theoretic economy, is always precisely the same invariable fraction of the total heat received from the source, no matter whether this heat be received in the form of latent or of sensible heat, and no matter what may be the nature of the elastic medium employed to operate the machine.

It has been shown, in fact, earlier in this report, that in a machine driven by heat which fulfils the conditions of the highest economy, there are four stages through which the elastic medium successively passes in performing one elementary portion of the work and coming back again to its original condition. These are, first, expansion at the superior temperature maintained uniform by constant addition of heat; secondly, expansion with depression of temperature, no heat being added or taken away; thirdly, compression at the inferior temperature maintained uniform by constant withdrawal of heat; and fourth, compression with elevation of temperature without addition or subtraction of heat, and with a final restoration of the original condition.

If we suppose the heat to be derived from an indefinite source at the superior temperature, denoted by A, and discharged, in so far as it is not converted into work, into an indefinite receiver maintaining constantly the inferior temperature and denoted by B, then any engine whatever, which, working under the conditions of highest economy, performs between these limits an amount of work, W, must receive from A the same amount of heat, H, and impart to B the same amount H', no matter what be the nature of the elastic medium through which the work is done.

For if this be not true, then there is a possibility that, of two machines which we will call C and D, both performing the same amount of work W between the limits, A and B, of temperature, and working under conditions of the highest economy, one may take more heat from A, and transfer of course more heat to B than the other. Let C, for instance,

take from A the amount of heat X, and transfer to B the amount X′. Let D in like manner take from A the amount Y, and yield to B the amount Y′, and suppose X to be greater than Y. X′ is less than X by the amount of work done; and Y′ is less than Y by the same amount. That is, $X - X' = W = Y - Y'$; and $X - Y = X' - Y'$.

Now as the machine C or D, receiving heat from A and transferring it to B, performs the work, W, it is only necessary to reverse the action of this machine, or to drive it backward, by force, in order to restore to A the heat taken from it; which in this case will be partly taken from B, and partly supplied by the conversion into heat of the force required to drive the machine backward. This force will of course be that represented by the work W. For simplicity, let it be supposed $X = 2Y$. Then if the machine C be driven backward, it will transfer to A an amount of heat equal to 2Y at every revolution; and to do this it will consume an amount of work equal to W. But the machine D, worked forwards, will furnish this same amount of work W, while taking from A only the amount of heat represented by Y. The machine C worked backward will therefore supply heat enough to work two machines like D, or one machine like D of double power. This machine of double power may then itself be employed to drive the machine C backward; and in this case it will keep up the supply of heat necessary to sustain its own movement, and will have the amount of work, W, constantly to spare. In other words, we shall have an efficient engine without any expenditure of any kind to maintain it; that is to say, a perpetual motion.

Differences of latent heat and differences of specific heat have therefore nothing to do with the question of relative economy, in the employment of different elastic media as substitutes for steam. It is accordingly unnecessary to examine the correctness of the statement of the inventor of the engine under consideration, on which he strongly insists as one of the reasons why it must be economical, viz., that the latent heat of ammonia in solution is only 126° C, contrasting this with the latent heat of steam which he states at 606°.5 C.[1] If it were true that latent heat is a mere dead weight, contributing nothing to work, then it would be equally true that the economical difference between two media would amount to the entire difference between the latent heats of the two; and in the case here presented, supposing the numbers correct, it would be enormously more in favor of ammonia than the inventor pretends to claim.

On the other hand, if it is true that the largest possible proportion of the heat which can be converted into work in the use of any medium whatever is expressed, as we have seen that it is, by the same invariable coefficient; and if this coefficient is a simple function of the extremes

[1] This is the latent heat of water supposing it evaporated at zero. As the evaporation in the steam-boiler takes place in fact at 100° C, or above, the latent heat will not exceed 537° C, to which, in computing expenditure of heat may be added the difference between 100° C and the temperature of the feed water. If the boiler is fed with the water from the condenser, 30° or 35° added to the latent heat may give the expenditure.

of temperature between which the work is done, then it follows that a great latent heat is an advantage, and not a disadvantage, in practical thermo-dynamics. For the coefficient gives the value of the heat which is converted into work in the form of a determinate fractional part of the whole heat received by the medium; and the greater this whole heat is the greater, of course, must be the fractional part. The formula is—

$$W=H\frac{T-T'}{T.}$$

W being the work, H the whole heat received, T the superior and T′ the inferior temperature reckoned from the absolute zero.

This H depends on two things: first, the capacity of the medium for heat while in the liquid state below the point of vaporization; and, secondly, the latent heat of the vapor. Let us suppose that we have a condenser which can be maintained at the low temperature of 60° F. This supposition is made not as ordinarily practicable, but as a possibility, in order to found a calculation upon a pretty large range of temperature. Let us now consider the amount of work which could be done by one pound of water evaporated at 212° F and condensed at 60° F, and compare it with the amount of work which a pound of ether would do between the same temperatures. We have for water, specific heat and density, unity; boiling point, 212°; and latent heat of vapor, 966 units.

Between 60° and 212° a pound of water absorbs.........	152 units.
And in vaporization at 212°.............................	966 units.
Total heat absorbed, or value of H=..............	1,118 units.

Hence, $W=1{,}118\,\frac{152^\circ}{672^\circ}=251.7$ units=195,224 foot-pounds, or nearly 100 tons raised one foot.

In the case of ether, we have—

Specific heat of liquid..................................	0.517
Specific heat of vapor..................................	0.481
Boiling point under atmospheric pressure............	95° F.
Latent heat of vaporization..........................	162.8 units.
Density of liquid......................................	0.716

From these data we find the total heat absorbed between 60° and 212°, thus:

Between 60° and 95°, 35°×0.517.......................	18.095 units.
In vaporization...	162.8 units.
Between 95° and 212°....................................	56.277 units.
Total absorbed, or value of H for ether..........	239.172 units.

And $W=239.172\,\frac{152^\circ}{672^\circ}=54.1$ units=41,415 foot-pounds, or hardly 21 tons raised one foot.

This result appears paradoxical, when it is stated that the pressure of ether vapor at 212° exceeds six and a half atmospheres, and that it continues to be nearly half an atmosphere even at the low temperature assumed for the condenser, (60°,) while steam at 212° has only an elastic force equal to one atmosphere, and at 60° is reduced to the sixtieth part of an atmosphere. The difficulty disappears when it is considered that it is not pressure only, but volume, and *change of volume* during change of temperature, which determines the work which can be done by heat operating through a given weight of any medium. At 212° a pound of ether vapor occupies but about one cubic foot, (0.9952 cubic foot,) while at the same temperature a pound of steam fills a bulk of 26.36 cubic feet. At 60° the ethereal vapor will be dilated to a bulk of only 10½ cubic feet, while the steam will have expanded to 1,200 cubic feet. Suppose one pound of each of these vapors to occupy a cylindrical space which it is capable of filling to a depth of one foot, the cross-section in the case of steam would be 26.36 square feet, and in the case of ether vapor 0.9952 square foot. If, then, these vapors are further supposed to be confined in these cylindrical cavities by movable pistons, the absolute pressure exerted by them severally upon these pistons will be—

For steam, 26.36 sq. ft. $\times$ 1 atm. $=$ 26.36 $\times$ 2116.8 lbs. $=$ 55798.848 lbs.
For ether $=$ 0.9952 sq. ft. $\times$ 6.5 atm. $=$ 0.9952 $\times$ 6.5 $\times$ 2116.8 $=$ 13693.156 lbs.

Thus, the absolute pressure which measures the possibility of doing work is four times as great in the case of the pound of steam as in that of the pound of ether. And in expanding between the limits, 212° and 60°, the pound of steam enlarges its bulk forty-six times, while the expansion of the ether is not equal to eleven. On both these accounts water will have the advantage of ether as a liquid to be used in elastic vapor engines.

But as in practice expansion is carried only to a limited extent, it may be more satisfactory if we test the effects of the two vapors on the supposition that each increases its bulk by expansion to the same proportional extent, as, for instance, in the ratio of one to two. Ether vaporized at the temperature of 212°, and expanded with falling temperature to double its bulk, will have a resulting pressure of very nearly three atmospheres. If we suppose the work done in the meantime to be equivalent to that which the mean of the initial and final pressures, continued constant from the beginning to the end of the movement, would be capable of doing, the work of expansion will be—

	0.9952 $\times$ 4.75 $\times$ 2116.8 $=$ 10, 006 foot-pounds, nearly.
To which add work of enlargement by vaporization	13, 693 foot-pounds, nearly.
Total work, ether vapor at 212° to twice its volume	23, 699 foot-pounds, nearly.

In the case of steam, expansion to twice the volume will reduce the pressure to 990 pounds per square foot; and if we take, as before, the

mean of the initial and final pressures, it will give us an equivalent constant pressure of 1,553 pounds. The work done by the pound of steam during expansion will then be—

	$26.36 \times 1{,}553 = 40{,}937$	foot-pounds, nearly.
And that done during vaporization	$= 55{,}799$	foot-pounds, nearly.
Total work, steam at 212° to twice its volume	96, 736	foot-pounds, nearly.

Where the same ratio nearly is manifest as before, steam performing more than four times the work of ether vapor.

It may be observed that the work actually done during expansion is not so great as the computation, founded on the assumption of a constant pressure equal to the arithmetical mean between the initial and final pressures, makes it; but the error of the result falls in the same direction in both cases, and, for the purpose at present in view, is not important in either.

The conclusion we arrive at is, that steam, as a vehicle for heat in machines, is preferable to ether vapor, and generally to the vapor of any liquid which absorbs in evaporation a less amount of latent heat than steam, so far as the physical properties and relations of the vapors themselves are concerned. And it is obvious in this comparison that, other considerations apart, the smaller weight and still smaller bulk of the liquid which it is necessary to use in order to secure a determinate amount of work when water is employed, will always be a sensible advantage on the side of steam. On the other hand, the waste of heat in furnaces, against which remedies are always more difficult of application in proportion as temperatures are higher, will probably be less with the more volatile liquids than with water, so that an ammonia engine may very possibly, or even probably, be an economical and a useful one; but this will not be because the latent heat of the gas, as liberated from the solution, is less than that due to its evaporation from the liquefied state—say 900 units—but because it is not so.

The ammonia engine, employing the aqua ammonia of commerce, works between the extreme temperatures of 230° F and, say, 100° F, and is capable of utilizing a fraction of the heat received, represented by the difference of these temperatures=130° divided by 460°+230°=690°, being the temperature at the upper limit reckoned from the absolute zero. This fraction is 0.188, or nearly nineteen per cent.

A steam-engine working between 300° F and 120° F (in the condenser) would, theoretically, be able to utilize $\frac{300^\circ-120^\circ}{460^\circ+300^\circ}=\frac{180^\circ}{760^\circ}=0.2474$, or nearly a quarter of the heat. But if discharged after dilating to four times its original bulk it will produce only half the useful effect above computed; that is to say, something over twelve and nearly twelve and a half per cent.

Neither the one nor the other of these engines will probably produce,

in actual practice, the amount of useful effect here credited to them. The steam-engine may give ten per cent. and the ammonia engine twelve. But it is not here that we shall find the source of the practical economy realized, if it has been realized, in the substitution of ammonia for steam. This economy probably results mainly from the practicability of maintaining the pressure in the boiler with a less intense furnace heat; and the gain is not in the diminished heat required to produce a given work, but in the diminished waste in that portion of the heat which does not enter the boiler or contribute to the work at all.

IV.—ROTARY STEAM-ENGINES.

No effort has more persistently occupied the ingenuity of inventors than the attempt to produce rotary motion by the direct action of steam. The varieties of rotary engine already produced are almost infinite in number, and every year brings new competitors of the same class for the approbation of the industrial world.

The only advantages, however, which can be claimed for a rotary over a reciprocating engine are a greater compactness of form and a possibly superior simplicity of construction. If in this last particular any proposed rotary fails, it may be safely assumed that it will never come into general favor. Compactness of form is desirable in the engines employed for purposes of locomotion, whether upon land or water; but in most other situations compactness is an advantage of secondary importance. It is to be noted, however, that, as yet, no rotary engine has been constructed possessing anything approaching to the power necessary for ocean or even for river navigation; and hence that invention in this direction has, as yet, accomplished nothing of what is most desirable, and what may be said to be really needed.

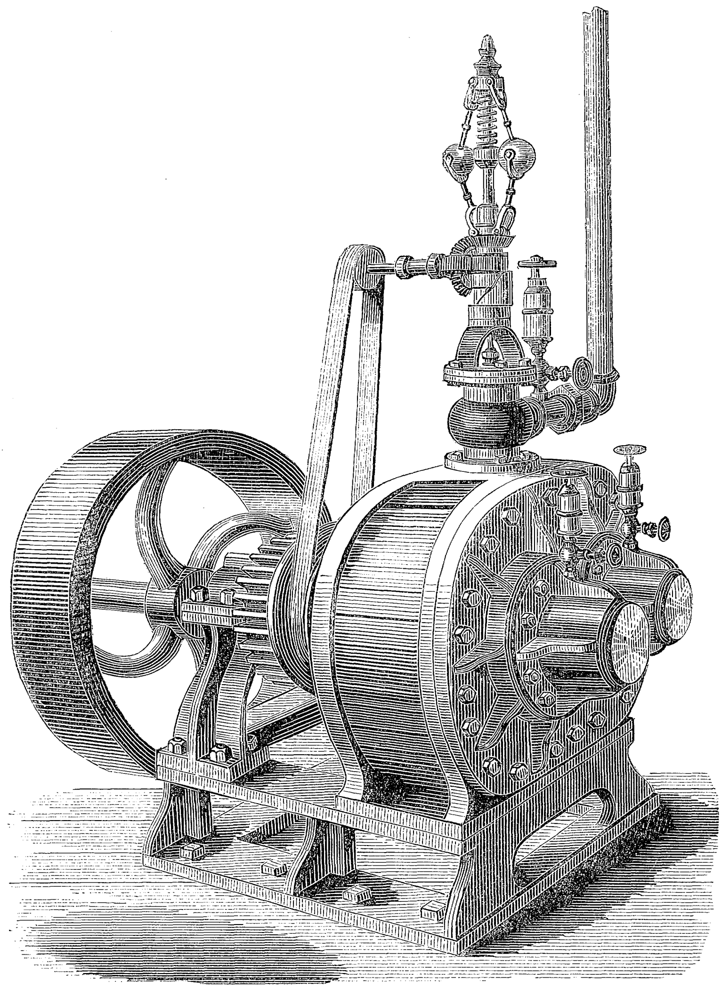
The principal reason of the imperfect success which has attended this description of effort is probably to be found in the great difficulty of securing a satisfactory packing of the piston without excessive friction, or one which should continue to perform well permanently. A similar difficulty exists in regard to the fixed (or occasionally movable) fulcrum, against which the steam must react in order to move the piston. On this account there is scarcely a single rotary engine in existence in which there is not great loss of effective pressure in consequence of the presence of steam behind the piston, and not one which could bear enlargement to the dimensions required to propel an ocean steamer without such loss on this account as to make it economically unavailable.

THE BEHRENS ROTARY ENGINE.

The Exposition has presented several forms of rotary engine which seem to be superior to most of their class. Of these the most remarkable is an American invention, patented in this country in 1866, and subsequently in Great Britain, France, and Belgium. The construction of this engine can hardly be explained without reference to figures. Its

general external appearance is represented in the perspective view annexed, Fig. 9, and its interior is shown in section in the several figures, 10, 11, 12, and 13.

Fig. 9.

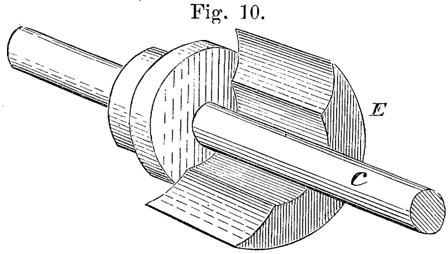


Behren's Rotary Engine.

It will be seen that there are in the same solid casting two cylindrical cavities which overlap each other. In the centre of each cylinder is a solid cylindrical core. Between each of these cores and the surface of the corresponding cylinder is a piston of peculiar shape, being part of a solid ring, filling up the intermediate space as far as it goes, and fitting both to the cylinder internally and to the core. These pistons are firmly attached to axes, which appear in section at C and C′ in the figures.

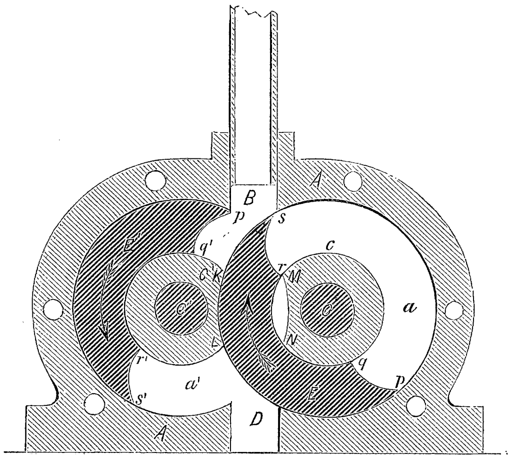
The manner of attachment is shown in the perspective view of one of

Fig. 10.



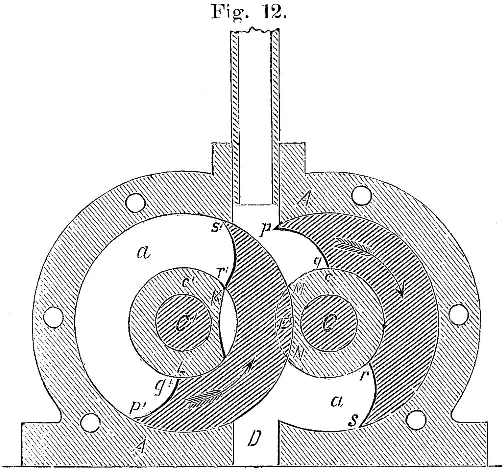
the pistons with its axis in Fig. 10. The axes are connected externally to the cylinders by equal gear-wheels, so that they move simultaneously and with equal velocities. The two centres of motion, C and C′, are distant from each other about two-thirds of the common diameter of the cylinders; and the cores c and c', which in their entire dimensions would be too large to allow the pistons to revolve, are reduced on the inner sides to a proper curvature to fit the piston exactly as it passes. Steam is introduced through the tube B and discharged through D. In Fig. 11 it will be seen that the pressure will be on the concave face of E′, producing motion in that piston, while it will be directed to the centre of motion of E, which will therefore form the resisting fulcrum. The opposite state of things is shown in Fig. 12, in which E receives the propelling force, and E′ presents the resistance.

Fig. 11.



The simplicity of construction of this engine highly recommends it. Its large surfaces of contact, cylindrical in form, and therefore easily adapted to each other, render it little liable to loss of power by leakage, and make special artifices of packing unnecessary. It is obviously as well adapted to water or heated air as a motive power as to steam. If reversed in direction and driven by another motor it forms a most efficient pump. It can be used with steam expansively. It has no dead point, but will start equally well in any position.

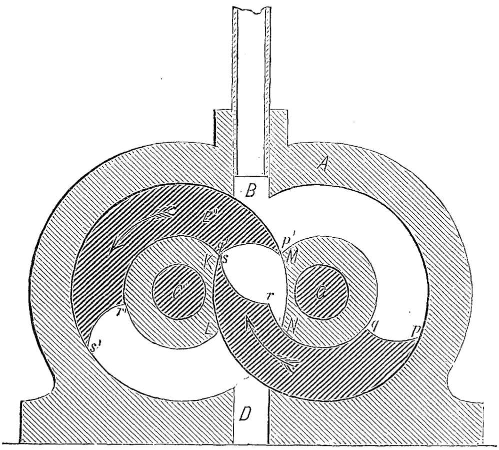
Fig. 12.



On the other hand, it may

be observed that it requires a larger amount of steam per revolution to drive it than engines of its class generally having the same cross-section of piston and the same diameter of cylinder. It will be seen, indeed, that, in order to bring the piston E from its position in Fig. 10 to its position in Fig. 11—that is to say, in order to effect a half revolution—the entire space marked *a* must be filled with steam, and also the cavity M N between the piston and the core. But if a line be drawn joining *p s* it will be a diameter of the cylinder. Hence, it is evident that considerably more than half the ring in which the piston moves has to be filled with steam every half revolution.

Fig. 13.



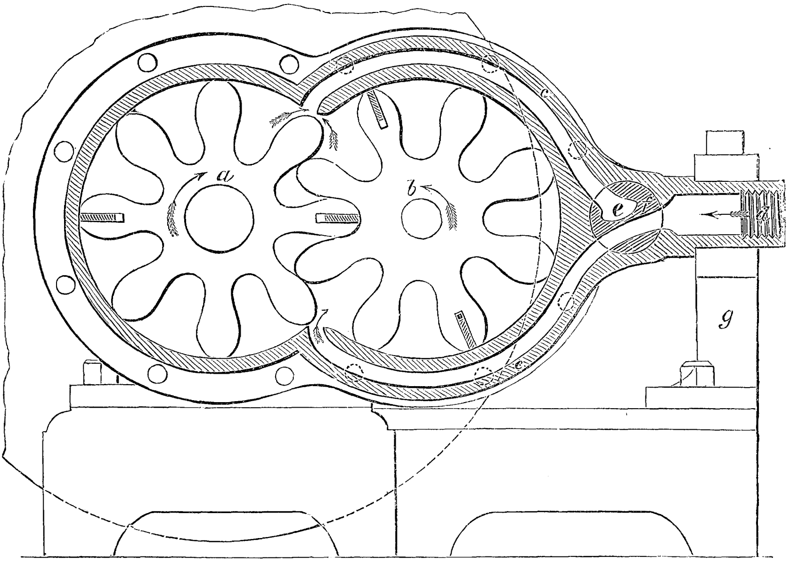
By assuming a position of the two pistons such as it is just as E is about to cease being the propeller and E′ is on the point of becoming such, which is represented in Fig. 13, the amount of space which has to be uselessly filled with steam may be shown distinctly enclosed by itself, as it occupies the closed cavity M N *r s*. It is not difficult to find the proportion which the capacity of this space bears to the total supply of steam during the half revolution. The curved face of the piston is practically cylindrical, and its radius may be taken to be equal, as it is nearly, to that of the core. Then taking the dimensions of the machine exposed, in which the interior diameter of the cylinder is sixteen inches and that of the core eight inches, the distance of the centres of rotation being eleven inches, we shall find by computation that fully fifteen per cent. of the steam admitted is productive of no effect. This is a disadvantage, but the other merits of the engine are such that it is probably destined to come into extensive use.

PILLNER & HILL'S ROTARY ENGINE.

Another rotary engine was exhibited by Messrs. Pillner & Hill, of Newport, England, which in external appearance presents some resemblance to the one just described. Like that it has two cylindrical chambers in the same casting, and two systems of rotary pistons. The rotating parts, however, which are shown in Fig. 14, herewith given, essentially differ from those of the Behrens engine, being in the form of two deeply indented gear wheels working into each other. These wheels by the close contact of their cogs prevent the passage of steam between them, and they are adapted steam-tight to the interior of their cylinders

by metallic packing in the tips of their teeth. Practically it is found to be sufficient to pack two teeth diametrically opposite to each other in each

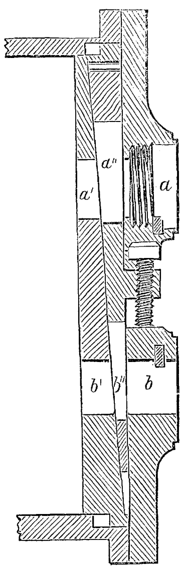
Fig. 14.



Pillner & Hill's Rotary Engine.

wheel. It is of course necessary that the wheels, at their plane extremities, should be in close contact with the interior walls of the cylinder; and in order to effect this, one of the cylinder heads is made adjustable, and may from time to time, if the moving parts by friction should work loose, be brought up by a screw acting upon a wedge-shaped plate, as shown in Fig. 15. Another mode of accomplishing the same object is by affixing plates to the lateral surfaces of the wheels, which plates are pressed outward by springs—that is to say, by a kind of metallic packing.

Fig. 15.



The manner in which the steam acts to produce motion in this machine will be understood from an inspection of the figure. The induction pipe is at *d*, and the discharge takes place at *e*. The steam enters the cylinder immediately under the centre of the system and presses on the teeth of both wheels in opposite directions. At the point where the teeth are interlocked, however, the surface pressed is practically equal to but a single tooth, while the contrary pressures are exerted upon two. The wheels therefore rotate in the direction of the arrows with a force equivalent to the balance of pressure—that is, to the total pressure on a single tooth.

The efficacy of this engine depends very much upon the accuracy with which the teeth of the gear wheels fit each other, and

upon the preservation of this close contact throughout the movement. It is affirmed that this object is completely secured, and that the effect of wear is to improve rather than to injure the performance of the machine. It is further affirmed that steam may be used in this engine expansively.

In the model exhibited, the diameter of the cylinders is 20 inches, the depth of the teeth nearly four inches, and the length 36 inches. The aggregate calculated horse-power, under a pressure of 40 pounds to the square inch and with 200 revolutions per minute, is nearly 140. This very greatly exceeds the power of any rotary engine heretofore constructed.

It hardly need be said that this engine is capable of being used as a water engine, or as a pump for liquids. And here the remark may properly be added that, although the invention is claimed as original by Messrs. Pillner and Hill, it was patented in this country thirty or forty years ago by Asahel Hubbard, of Vermont, as a water pump, and was manufactured on a large scale for that purpose at the works of the American Hydraulic Company, at Windsor. The principle was also embodied in a rotary fire engine, manufactured by the same company, which enjoyed an extensive popularity. Many of these engines, constructed in the company's works at Windsor, were sold and used in the principal cities of the United States earlier than the year 1836. The pump is yet in use in many parts of the country for domestic purposes, and it is believed that the manufacture is still continued.[1]

Messrs. Pillner and Hill have improved the packing of the machine, but in principle they have made no change whatever.

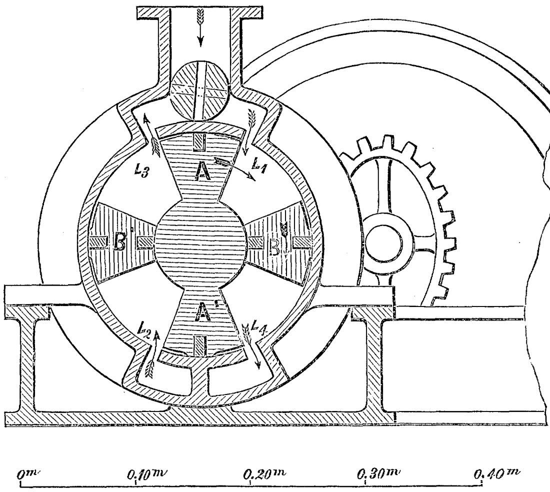
THOMPSON'S ROTARY ENGINE.

A third form of rotary engine, exhibited by Mr. R. W. Thompson, of Edinburgh, appeared to embody in its construction a greater degree of ingenuity and originality than has been shown in any invention of its class heretofore produced. It is called by the inventor a differential engine, for a reason which will appear when its operation is understood. This engine is represented in the figures which follow. Fig. 16 is a section through the cylinder at right angles to the axis. It will be seen by comparing these figures that there are two pairs of pistons, each pair being attached to a core which occupies but half the

[1] General Morin, in a passage in his treatise, "Des Machines et Appareils destinés à l'élévation des Eaux," encountered since the statement in the text was written, describes this identical pump, and furnishes a figure of it, which essentially resembles the engine of Messrs. Pillner and Hill, and concludes with the remark: "This arrangement, early known, has been produced in our days as new. (See the collection of Grollier de Servière, Lyons, 1719.") The correspondent of the London "Engineering," at the Exposition, also remarks of it, "There is nothing new in this contrivance which is a reproduction of Murdoch's rotatory engine of the last century, and it in its turn is a copy of the Machina Pupperheimana, figured as a pump in Leupold's *Theatrum Machinarum*, published in 1727." Thus it appears that neither the American nor the British invention can claim the merit of originality.

length of the cylinder in the direction of the axis. Each pair of pistons is thus attached to its own cone only for half the piston length, while the other half projects over the core belonging to the other pair. Neither pair of pistons can therefore pass the other,

Fig. 16.



though they may come into contact. Each pair of pistons has its independent shaft, and externally to the cylinder each of these shafts carries an elliptical gear-wheel, which works into an equal and similar wheel upon a shaft parallel to the piston shaft. This second shaft, which

Fig. 17.

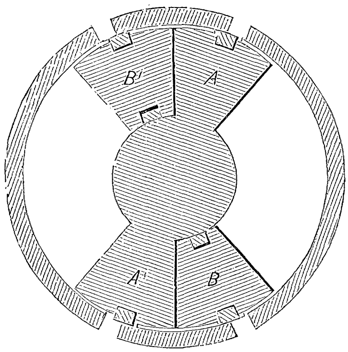
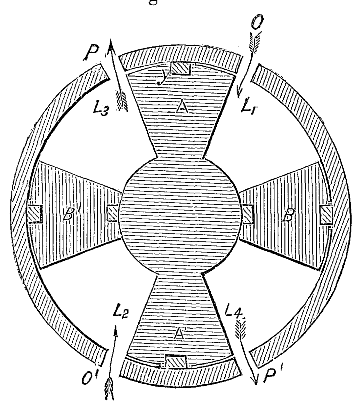


Fig. 18.



is the working shaft, is provided with a fly-wheel regulator. The relative position of the shafts and the connection of the gearing is shown in Fig. 19. The working shaft carries, of course, two elliptical gear-wheels;

and these are set with their major axes at right angles to each other. The elliptical wheels upon the piston shafts have their longer axes at right angles to the pistons. Supposing then the engine to be in that point of the revolution which is illustrated in Fig. 16, the nearer pair of its pistons will be vertical and the more distant pair horizontal. If we disturb it from this position, by turning the fly-wheel by hand, it will be evident that the remoter piston will be forced to revolve faster than the nearer one, because the gear-wheel on the working-shaft acts in the former case by its longest radius, and in the latter by its shortest, while the opposite is true of the wheels on the piston shaft. The pistons will therefore approach each other on one side and become more widely separated on the other, assuming ultimately the position shown in Fig. 17. It is evident, however, that the velocity of rotation of the remoter piston will be regularly retarded and that of the nearer accelerated, so that after a time it will be the nearer which will move fastest and the more distant which will move slowest. From the position shown in Fig. 17, therefore, the pistons will at first separate, and afterward come together again by their opposite faces.

Now if we suppose the pistons to be moved from the position shown in Fig. 18 to that shown in Fig. 17, we shall see that the spaces L' and L_2 will be enlarged and will draw in air through O and O′, while at the same time the spaces L_3 and L_4 will be reduced in capacity so that the air will be expelled from them. Or if water should be supplied through O and O′, the machine might be used as an aspiring or forcing pump, the power operating it being applied through the shaft which carries the fly-wheel. If, however, instead of sucking in the air or water through O and O′, we force it in with a pressure superior to that of the atmosphere, motion will take place in the opposite direction, and the machine will become a motor. Each piston, with its shaft and gear-wheel, may indeed be regarded, at any given moment, as a lever, exerting an effort to turn the working-shaft; but each exerts its effort in an opposite direction to the other. The power applied is the same in both cases, since it is the pressure of the steam on the equal surfaces of the pistons; the arm of the lever on the side of the power is also the same for both. The effect, however, is generally unequal, because the arm on the side of the resistance is usually greater for one than for the other, and, moreover, the distance of the point of application of the force from the axis of the working-shaft is also variable. This shaft will, therefore, turn with a force equal to the difference of the opposing forces; and this is the feature from which the engine takes its name.

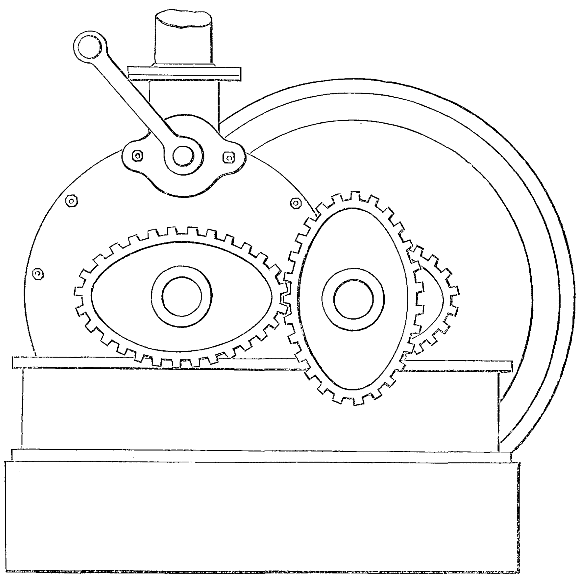
The extent of the relative movement of the pistons will depend, of course, upon the degree of ellipticity of the gear-wheels. On supposition that those wheels were circular, there would be no relative change of position at all.

When the ellipticity to be used has been determined upon, it is easy to calculate, or to find experimentally, what will be the limit of nearest

approach of the pistons. This having been ascertained, it is important that the pistons themselves should receive such form and dimensions as to cause them, at the moment of nearest approach, to come into absolute contact, in order that there may be no dead or useless space for the waste of steam. It is this consideration which has caused the piston in this engine to be constructed as shown in the figures, in the form of sectors. But as the ways for the entrance and discharge of steam have to be placed at a certain distance from each other, for a reason which will presently appear, it is necessary that the piston should not be in full contact with the cylinder except in the middle point of its bulk, where contact is secured, as shown in the figures, by a metallic packing.

The point of nearest approach will be that at which the velocities of the two pistons become equal; for as they approach while the following piston moves fastest, they must begin to separate so soon as the leading piston begins to gain. It may be said to be self-evident, and at any rate it is easily proved, that when the velocities become equal, the radii which are for the moment engaged in the gear-wheels on the side of the working shaft must be equal to each other; and also that those engaged at the same time on the side of the piston shafts must be equal to each other. The first of these conditions requires that the major axes of the ellipses on the working shaft should be at that moment inclined 45° to the line connecting the centres of motion of the parallel shafts. The

Fig. 19,



End view of Thompson's Rotary Engine.

angle simultaneously made by the major axes of the ellipses on the piston shaft, will be the limit of nearest approach of the pistons.

If we suppose the engine to be in the position represented in Fig. 19, and call the piston-wheel which is presented horizontally, A; the wheel into which it works, B; the remoter wheel on the same shaft, C; and the remoter piston-wheel, D; then, according to what has just been stated, B and C must advance 45° to bring the pistons to the position of nearest approach. The proof of this is as follows:

The relative angular velocity of wheels gearing into each other is inversely as their radii drawn to the point of contact. If these radii are represented for the several wheels, in the order in which they have been named above, by the letters R_1 R_2 R_3 R_4, and if the angular velocity of A at any moment be represented by φ, that of B or of C, which is the same, by θ, and that of D by ω, then we shall have

$$\varphi : \theta : : R_2 : R_1 \text{; and } \theta : \omega : : R_4 : R_3.$$

$$\text{Whence } \theta = \frac{R_1}{R_2} \varphi = \frac{R_4}{R_3} \omega \quad \text{and } \omega = \frac{R_1 R_3}{R_2 R_4} \varphi.$$

And since φ and ω must be equal at the moment of nearest approach, we have at that moment

$$R_1 R_3 = R_2 R_4.$$

Now if the major and minor axes of the wheels be represented by a and b, it is evident from an inspection of the figure that the distance between the centres of motion of either of the pairs of wheels which gear into each other, must always be equal to $a + b$, and therefore that

$$R_1 + R_2 = R_3 + R_4 = a + b.$$

If in this equation we substitute the value of R_1 from the preceding, we shall deduce as a consequence, $R_2 = R_3$; that is to say, the engaged radii of the wheels on the working shaft are equal when the pistons are at the point of nearest approach.

If two equal and similar ellipses be superposed with their major axes at right angles, the points of intersection of their circumferences will mark the position of equal radii; and this position must necessarily bisect the right angle.

When the semi-axes a and b are given, we may calculate the angle made by R_1 and R_4 with the major axes of their ellipses, at the same moment of nearest approach. The general expression for the square of the radius of an ellipse, is

$$R^2 = \frac{a^2 b^2}{a^2 - e^2 \cos^2 \varphi},$$

in which e represents the eccentricity, and φ is the angle made by the radius with the major axis a.

By measurements made upon a wooden model of this engine placed by the side of the engine itself which was in operation in the exposition building, the minor axis of the ellipses appeared to be to the major in the ratio of two to three. By substituting these numbers for b and a in the foregoing formula, and putting $\varphi = 45°$ we shall find the values of R_2 and R_3 to be 2.38 nearly. Then as $R_1 + R_2 = a + b = 3 + 2 = 5$, we deduce $R_1 = 2.62$.

The general equation transformed gives

$$\cos^2\varphi = \frac{a^2 \, (R^2 - b^2)}{R^2 \, e^2}.$$

And by substituting the value found for R_1 in the place of R_1 and for a and b their values as before, we shall find the value of φ to be almost exactly 30°.

As this angle is reckoned from the position represented in Fig. 16, which is the position of maximum relative velocity of the pistons, it represents but half the angular movement of the wheel A, or of its corresponding pistons, since leaving the last preceding point of equal velocity. The total movement of A therefore between two such successive points, during the period in which its major axis passes the horizontal is 60°. The relative movement of D during the same time, or its total gain on A, amounts to 120°.

From these computations it results that the pistons should fill 60°, each, of the space in the cylinder, and that the vacant space between them, when in the position shown in Fig. 17, should be also 60°. The larger the disparity between the semi-axes the larger will be this vacant space, and the smaller will be the pistons.

If we consider the expenditure of steam necessary to drive this engine, we shall observe that each of these spaces of 60° has to be filled four times during each complete revolution of the working shaft; that is to say, eight sectors of the cylinder, having each 60° of arc, must be filled in the same time; the whole amounting to one and one-third times the capacity of the cylinder.

Each piston is propelled in the direction of progress through two-thirds only of the revolution. If during the remaining third it were unacted upon either way, this engine, considering the effect of a single piston only, would be only two-thirds as effective, with the same pressure and the same number of revolutions, as one exposing the same piston surface, and constructed on the plan of Pillner and Hill. But during the remaining third it is urged in the opposite direction with the full force of the steam. This negative effect must be subtracted from the positive, so that in truth the efficacy of the engine is reduced to one-third instead of two. On the other hand it has two pistons working simultaneously, so that, as compared with a Pillner and Hill, of similar piston surface, its performance is as two to three. The expenditure of steam being, however, one-third greater, it is economically but one-half as efficient. It is recommended nevertheless by its great compactness, which adapts it to operations in which economy of space is important; and it is stated by the inventor to be already in use in various parts of the world in driving machinery, working steam-cranes on shipboard and hoisting heavy weights.

The figures show the manner of admission and discharge of steam sufficiently well to require no extended explanation. There are two openings at the top, and two at the bottom of the cylinder, of which

the distance from centre to centre should be exactly equal to the breadth of the piston. Through one of these the steam enters, while it is discharged through the other, as shown by the arrows. A cylindrical valve, acting as a kind of two-way cock, shown in cross-section in Fig. 16, gives direction to the entering and escaping steam. This is controlled by a crank, shown in Fig. 19. In the cross-section of this valve, Fig. 16, is shown its position when the steam is shut off. It is manifest that the engine will rotate in either direction indifferently, and that it admits of reversal with extreme simplicity. It has, however, four dead points in every revolution, and requires a fly-wheel of considerable weight. Like most rotaries, it can be used as a water-engine or as a pump.

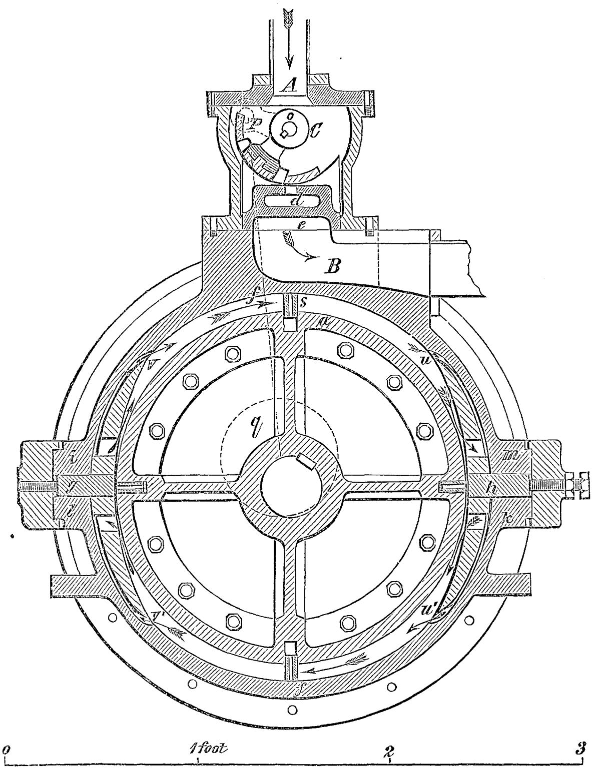
THE SCHEUTZ ROTARY ENGINE.

Mr. Edward Scheutz, of Stockholm, exhibits a design of a rotary engine, of which an idea may be gathered from the accompanying figure (Fig. 20) which is a section through the cylinder at right angles to the axis. The cylinder itself is contracted on two sides diametrically opposite to each other, while the rotating body, *a*, which carries the pistons, preserves its circular form. The pistons are fixed in sockets in which they slide freely, being kept in contact with the cylinder by springs placed behind them. In passing the contracted diameter of the cylinder, they are pressed down completely into their sockets, and in the wider portions they project. There are fixed also, in the cylinder itself, at the extremities of the reduced diameter, sliding plates, *g* and *h*, which are pressed inward against the revolving body by springs, so as to maintain there always a steam-tight contact. The steam enters at A, passing first into a box C, in which is an oscillating valve of distribution *o*, employed when steam is worked expansively, and controlled by a crank indicated by dotted lines at *p*. This crank is operated by an eccentric on the working shaft, shown by the dotted circle at *q*, the connecting rod being indicated by the dotted line *p q*. When steam is used without expansion, this crank may be thrown out of connection, the oscillating valve being placed in position to allow the steam to pass freely from C into *d*; after which it is conducted by passages, which do not appear in the section, to the induction openings in the cylinder at *i* and *k*. The exhaust steam leaves the cylinder at *l* and *m* and is conducted to *e*, where it escapes into the eduction pipe B. The spaces *d* and *e* are openings in a slide valve, of which the cross-section is shown, which is moved by a lever externally to the machine, and enables the attendant to stop or reverse the motion. By means of this slide the steam may be shut off, or so directed that *l* and *m* may communicate with A, and *i* and *k* with B.

There is one other peculiarity which remains to be noticed, and it is the only one (except the oscillating valve *a*, which is unimportant) in which this engine differs essentially from a multitude of its class. The openings for the introduction of steam into the cylinder, and those for

its discharge, are double. The principal openings, *i k l* and *m*, are near the diameter of greatest contraction; but these are connected with others, *u* and *u'*, *v* and *v'*, which communicate with the cylinder at points

Fig. 20.



Rotary Steam-engine of E. Scheutz.

where the contraction begins. The advantage of this is, that whenever a piston, as *s*, moving in the direction of the arrow, and therefore under a full press of steam on the side towards *v*, passes the point *u* in its progress, the space both behind and before it in the cylinder communicates equally with the eduction pipe, and the pressure is relieved. In passing further on, therefore, from *a* to *h*, the piston is pressed into its socket with the minimum of frictional resistance. The same conditions exist as the piston returns to its salient position after passing *h*. This advantage is not gained at any expense of motive power, there being four pistons 90° distant from each other, while the distance from *v* to *u* does not exceed 90°. It also follows from this construction that there is no dead point, nor is there any dead space.

On the other hand, it may be observed, that the engine has the fault which has been fatal to so many of its kind, of requiring large motion of important parts within the cylinder; by which these parts, almost

invariably, work loose. In small models, the advance and recoil of the pistons may not be attended with serious evil, but the same can hardly be true when these pistons are required to be very large.

It will be further obvious that the width of the ring, in the direction of the diameter of the cylinder, into which the steam is admitted, cannot conveniently be made so great, in proportion, as other forms of rotary engines allow. It must nevertheless be confessed that there is ingenuity and merit in the contrivance for avoiding the excessive friction which, in many similar engines, is consequent upon the use of sliding pistons, and it is, therefore, to be regretted that the engine was exhibited only in design, and not in a working model.

BREVAL'S ROTARY ENGINE.

Among the many forms of rotary engines which have originated in France, but which were not exhibited, is one by Mr. Breval, of Paris, which is sufficiently ingenious to merit a passing notice. It is represented in cross-section.[1] A is the cylinder. Internally it will be seen that the same casting presents two unequal cylindrical bores. B is a cylinder revolving within the larger bore, having a diameter exactly double that of the smaller cylinder C, which revolves within the lesser bore. These cylinders fit steam-tight, by their plane extremities, to the ends of the hollow cylinder internally, and they are in intimate contact with each other during most of the revolution. By a system of gear-wheels, external to the cylinder, C is made to revolve twice as fast as B, so that the surfaces roll on each other without friction. B carries two teeth, which are the pistons of the engine, and which are fitted to the interior cylindrical surface of A by metallic packings. A portion of the cylinder C is removed, in order to allow the teeth of B to pass. The surface of the recess thus formed is epicycloidal, so that the tooth maintains close contact with it during the passage. The gearing is necessary, in order to insure the presentation of this part of the circumference of C, exactly at the moment when the tooth is ready to pass. In order to understand the action of the engine, attention should be directed to the positions of the teeth, indicated at *a* and *a*. Steam being admitted at *e* behind *a*, while the cylinders B and C by their contact prevent escape in that direction, the piston is driven forward in the direction of the arrow until it reaches the position a'. At this point the steam escapes through *c*; and the action of the induction valve is such as for a brief interval to cut off the supply at *e*. But at the same time the other tooth will be passing the cylinder C; and this will presently present itself in the position *a*, at which instant the steam will again be admitted.

[1] Owing to an accident the wood-cut referred to in this description is wanting, and cannot be replaced without stopping the press longer than is desirable. The reference letters are retained in the text for convenience of description.

The cylinder C has a metallic packing at the points marked *d*.

On the opposite or lower side of A, in the mean time, the first tooth completes its revolution without further contributing to the propelling power. The lower half of the ring has an opening *q* near the cylinder C, which communicates with the atmosphere or with the eduction pipe E, so that the pressure is equalized on the opposite sides of each piston during the second half of its course. By employing a second cylinder like C, at the opposite end of the horizontal diameter of A, both pistons might be made effective, and a double power obtained, but it would be at a considerable increase of dead space. In the construction shown, there is dead space between the horizontal position of the piston and the position shown in dotted lines and marked *a*. This would be doubled if a second cylinder C should be introduced, since the discharge would have to be at *q*, and at a corresponding point diametrically opposite to *q*, while another induction opening would be required just below *c*. Two pistons would therefore give, while in action, a double power, at the expense of a double period of inefficiency, and a double amount of dead space for each.

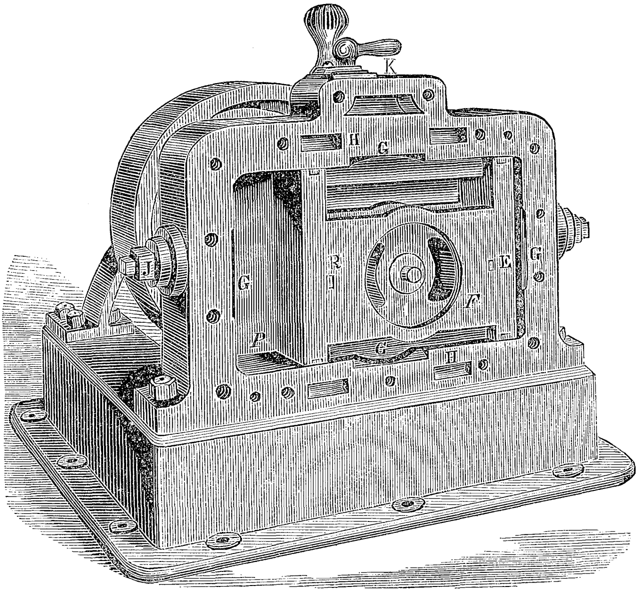
The manner in which the admission of steam is managed, so as to commence only when the piston is at *a*, and to cease when it reaches *c*, is shown at *o*. J is a circular slide valve, which is kept in revolution on its centre by the gear-wheel *k* and the axis *n*. Its plane face is in contact with the wall of the valve-box, through which there is an aperture *o′* communicating with the interior of the cylinder through *e*. The disk is pierced throughout a considerable part of a complete circle with an opening *o*. So long as this opening is in any manner superposed upon *o′*, steam will be forced to enter the cylinder; but in the position shown in the figure, which is that which the valve has when the piston is horizontal, it is the unperforated part of the disk which overlies *o′*, and therefore the steam is shut off, and will continue so until the extremity of *o* reaches *o′* again. It is easily seen that by changing this valve disk for one less extensively perforated, this engine admits of being worked expansively. The simplicity of its construction is greatly in its favor. The principal objection to it is the amount of dead space it necessitates; but this is hardly more than exists in the Behrens engine.

ROOT'S DOUBLE-PISTON SQUARE ENGINE.

One of the most compact forms of steam motor presented by the Exposition was exhibited by the Root Steam-Engine Company of New York, and called by them the double-piston square engine though classed by the jury among the rotaries. Externally it has the appearance of one, rotation seeming to be directly produced without the intervention of any perceptible reciprocating or crank motion. By examining the interior, this effect is seen to be caused by two pistons rectangular in form, work-

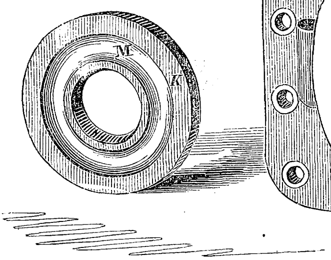
ing at right angles to each other, and one within the other. Fig. 21 shows the arrangement. The larger or external piston is in the form of a rec-

Fig. 21.



Root's Double-piston Square Engine.

tangular frame working horizontally within a box of similar form, and is marked E. The smaller, marked F, works vertically within E. Through the centre of F passes the crank pin, which is carried around



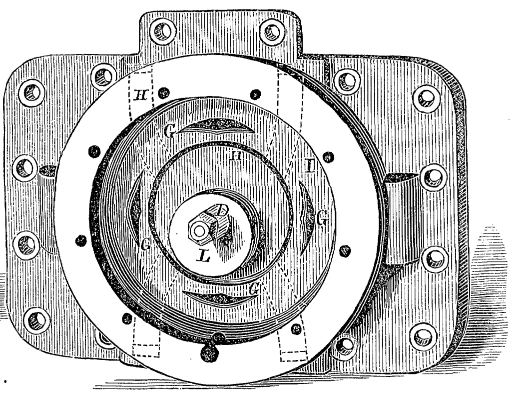


Fig. 22. Fig. 23.

in a circle by the simultaneous action of both pistons. The smaller piston is shown separately in Fig. 24, and the crank in Fig. 25. Fig. 23 represents a plate which closes the steam-box or cylinder, Fig. 21, the surface presented being that which is external when the plate is in place.

The circular chamber shown in Fig. 23 is the valve box, which is closed by another plate screwed over it. The steam, which is admitted from above, enters at K and is conducted to the valve-box by a passage in the plate Fig. 23, not seen. From the valve-box it is admitted to the cylinder through the openings marked G, whenever they are uncovered by the valve. Through the same openings the exhaust steam escapes, not into the valve-box, but into the annular channel marked H, when the valve-plate, which is countersunk on its lower face for this purpose, covers them. A single valve-plate serves for the entire distribution. It is shown in Fig. 22. Its form is circular, and it has an annular counter-sink M on the face applied to the valve face I, designed, as just stated, to allow the exhaust steam to escape into H. From H this steam is conducted through channels shown in dotted lines to the openings marked H in Fig. 21, and thence through channels in the body of the casting to J, or to the corresponding point at the other end of the cylinder, where the eduction pipe is to be attached. The valve plate K is fitted to the eccentric on the centre pin D, and this eccentric is carried round by a stud in the end of the crank, seen both in Fig. 21 and Fig. 25, which enters an arm on the other side of the plate Fig. 23, for which space is made in the central circular recess of the smaller piston. The valve is in contact by its circumference with the internal cylindrical surface of the valve-box, on which it rolls during the revolution, and it opens and closes the steam-ports successively as it passes. This contrivance is remarkable at once for its simplicity and for its ingenuity.

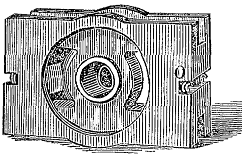


Fig. 24.

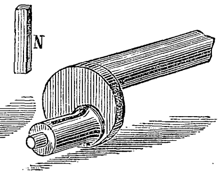


Fig. 25.

The pistons are packed by means of rectangular bars of steel placed in grooves on their edges and pressed outward by springs. One of these is shown in Fig. 24.

This engine is without dead points and almost without dead space, the pistons working up to the ends of the chamber and to each other, with only a slight recess at G, G, Fig. 21, for clearance.

It is strong in all its parts, not liable to derangement, and of almost unexampled simplicity of construction. Of the minor steam-engines it is the only one which received from the jury a higher distinction than an honorable mention.

Of its actual performance in practice, an opinion may be formed from a statement made by the exhibitors in their illustrated catalogue. This statement is to the effect that one of these engines working a pile-driver in New York raises a weight of 2,200 pounds 36 feet in six seconds, a performance which is equivalent to twenty-four-horse power, (the statement says twenty-*two* or upward.) The combined piston surface is 56 square inches, the length of stroke five inches, and the number of revolutions per minute 150. The steam pressure is not given, but with these data and

the observed performance it may be computed. To raise 2,200 pounds 36 feet in six seconds, indicates a force of 792,000 foot-pounds per minute. The course of the pistons per minute, making 150 double strokes of five inches each, is 125 feet. The total pressure on the pistons must therefore amount to 6,336 pounds, which is equivalent to 113 pounds per square inch, or more than $7\frac{1}{2}$ atmospheres. And as the observation gives, of course, the net horse-power, no account being taken of friction in the engine or in the hoisting apparatus, the actual aggregate force of the engine ought to be considerably above that just stated, and the steam pressure correspondingly greater; or, say, pressure of eight atmospheres. This exceeds the ordinary working pressure of steam-engines, and hence there would appear to be somewhere a mistake. An experiment lasting but for six seconds will not ordinarily be timed with sufficient accuracy to serve as a test of the power of a motor; and possibly the altitude to which the weight was raised may have been assumed to be greater than the fact. There can be no doubt, however, of the admirable performance of these engines, and there seems to be no reason why they should not be constructed on a much larger scale than has yet been attempted.

V.—HYDRAULIC MOTORS.

The usual and generally the most eligible mode of employing water power is to apply it to the circumference of some description of wheel. Occasionally, however, it may be more advantageous to use it as steam is used, for the purpose of moving a piston. This mode of application is especially adapted to the use of a small supply of water having a large fall.

HYDRAULIC ENGINES.

Hydraulic engines may be constructed on the plan of steam-engines, either reciprocating or rotary. Some modifications will be necessary in the construction of the parts, in order to accommodate them to the different physical properties of the denser fluid. The induction and eduction pipes, for instance, should be larger than are required for steam, and it is more important also, in this case, that they should have no abrupt angles. Freer valve ways also are necessary; the eduction valve should open very promptly at the end of the stroke, and the induction valve should not close until the stroke is quite completed—that is to say, the influx should cease and the efflux should begin exactly at the same moment. Any material error in making the adjustments designed to accomplish this end, or any imperfect working of the machinery which prevents its attainment, will produce concussions, *coups de bélier*, *water-ram blows*, as they are called by the French, which will very certainly be injurious and which may be destructive. This is a matter, therefore, which requires and receives the inventor's first and most careful attention. In the hydraulic engines which have been most extensively introduced and most successful in practice, provision is made by relief valves

or other expedients to mitigate or obviate the evil resulting from this cause; but in so far as it is possible, by the adjustments of the machine itself, to permit the column by which it is operated to maintain a uniform velocity, both true economy of power and durability of parts will be best consulted. In the case of steam, attention to the particulars here pointed out is not so rigidly necessary; the difference arising from the fact that steam is eminently compressible, while water is so only to a degree which for ordinary purposes may be regarded as insensible.

It is only in some special industries that hydraulic engines have as yet been extensively introduced. In the British foundries they have been found very convenient and efficient, chiefly in the working of cranes and other heavy machinery. They have also been employed occasionally for the drainage of mines. A remarkably ingenious illustration of their possible usefulness for this latter purpose may be seen at present in operation at Huelgoat, in Brittany. The great water engine of Huelgoat, the invention of Mr. Juncker, engineer of the mines it is employed to drain, has been often described. A very full description is given by Mr. Delaunay in his Mechanics. This engine is single-acting, and it acts directly to lift the piston of the pump by which the water is drawn from the mines. It makes five and a half strokes per minute, the stroke being two and a half metres, or more than eight feet in length. The piston-rod is 230 metres (767 feet) long, and it weighs 16,000 kilograms—1,000 kilograms being about one ton. The power of the engine is derived from a source at a height 110 metres (370 feet) above its own level.

In this case, though the direct application of the power reduces the engine to its simplest form, yet the great inertia of the moving columns of water requires that their movements should be very carefully regulated. In a reciprocating engine there are moments of rest, and successive periods in which the piston moves in opposite directions. When the driving force is communicated to a machine through a crank, it is a favorable circumstance that crank motion necessarily retards the movement of the piston toward the end of the stroke and brings it insensibly to zero; while at the beginning of the stroke it in like manner favors gradual acceleration. But in the engine at Huelgoat, without some mechanical contrivance to reduce very gradually the volume of inflowing water toward the end of the stroke, the piston would reach the limit of its course with its maximum velocity, and the sudden arrest of its motion would produce a concussion which no strength of materials could resist. The ingenuity and the simplicity of the contrivances by which this powerful machine is made to regulate automatically its own motions, so as to prevent the occurrence of the slightest perceptible shock, has excited the highest admiration of every engineer who has examined its construction.

CARRET, MARSHALL & CO.'S WATER-ENGINE.

In the present Exposition the water-engines exhibited are few in number. One appears in the British department and two are presented in

the French. The British engine, which is that of Carret, Marshall & Co., of Leeds, is a cylinder and piston engine having a rather remarkable peculiarity. Considering that variations of the velocity of the column of water flowing through the machine are necessarily disadvantageous, even when unattended with shocks or concussions, since every arrest of the flow is attended with the loss of a sensible quantity of living force; and considering that, when reciprocating motion is converted into circular motion by means of a crank, the velocity of one or the other of these motions must be variable, while irregularity in the circular motion is inadmissible, the inventors have dispensed with the crank, and by a mechanical contrivance displaying considerable ingenuity have caused the force to act always tangentially to the circumference of a disk (or rather of a pair of disks) fixed upon the main arbor or working shaft of the machine. Thus, as the circular motion of these disks is sensibly uniform, that of the piston may be so likewise, and hence the influx and efflux of the water may proceed with an invariable velocity.

The contrivance by which this application of power is effected consists in a pair of toothed racks connected with the piston by a cross-head on the top, and constituting a continuation of the piston; these racks being sufficiently far apart to allow the working shaft to pass between them without touching. The racks gear into toothed sectors which receive from them a reciprocating motion, and which are furnished with a system of clamps which lay hold on the disks above mentioned when the motion corresponds with that of the revolution of the shaft, but release them when it is in the contrary direction. The admission of the water alternatively above and below the piston is effected by a slide-valve operated by a rod carried by the piston itself; and the flow of the water from the source is sensibly uniform in velocity not only during the stroke but during the change of direction of the piston. The object aimed at, viz., the prevention of shocks, is thus perfectly secured, provided the piston and the apparatus connected with it be light. The construction is therefore sufficiently well adapted to engines of small power, although the mode of securing circular motion seems to be unnecessarily complicated. In the engine exposed, the nominal power is one-sixth of a horse-power, the cylinder being five and a half inches in diameter, the stroke ten inches, and the water pressure three atmospheres. The price of such an engine is stated at 1,080 francs, or about $200. The inventors undertake to construct engines on the same model, of any desired power or dimensions. They give a list of dimensions and prices, which embraces a range of from two to seven inches in the diameter of the cylinder, and in which the prices vary from 600 to 1,640 francs. For movements which do not require transformation of reciprocating into circular motion, these little machines must be very useful, wherever a small stream of water is available with a pressure above that of the atmosphere. Thus they may be applied to the blowing of bellows for organs or for forges, to the working of pumps, the sawing of wood or stone, to polishing marble or glass, and

to many similar purposes. They are recommended by their neatness and safety, and also by their comparative cheapness.

PERRET'S WATER-ENGINE.

A reciprocating water-engine is presented in the French section of the Exposition by Mr. F. E. Perret. This is the most remarkable machine of the kind exhibited; and it has been thought worthy of a medal by the jury. Its construction presents some novelties, which hardly at first view produce a favorable impression. The essential parts of the engine are a cylinder and a double-acting piston. The motion is communicated to a working shaft in the ordinary way. The peculiarities consist in the manner of admitting and discharging the water. This is effected through openings at each end of the cylinder which occupy the greater part of its circumference and form a sort of annulus; there being left only enough solid metal to connect the end of the cylinder with the body. Thus the water is admitted to the interior from all sides. To facilitate this, the cylinder is entirely enveloped by a second cylinder, with a space intervening between the two, which is filled with the water of induction. The extreme portions of the working cylinder are turned very smooth externally in a lathe, and the ends of the enveloping cylinder are here contracted, and turned likewise on the inside, so as to make a joint as nearly as possible water-tight. Both these cylinders are enveloped completely by a third and larger one, between which and the second, there is a space for the escape of the water on its discharge. This cylinder and the second are cast in a single piece, and form one body. The extremities of the third, like those of the second, are adapted accurately to the surface of the first, but there is a space between the second and third at this surface, which is as wide as the annular series of openings above described in the first, by which the water is to be admitted into or discharged from the first, which is the working cylinder. It is obvious from this disposition of things, that in order that the machine may operate, either the inner cylinder must move backward and forward alternately, so as to present the openings which answer to its valves in front of the spaces which communicate with the supply and exhaust; or that the two external cylinders should move in this manner, while the inner one remains fixed. Mr. Perret has chosen the first of these methods, apparently because it presented fewest difficulties. But for an engine on a large scale, either seems objectionable.

The motion of the working cylinder through the small space which is required to effect the admission and discharge of the water, is accomplished by means of an eccentric upon the crank shaft, which is set at right angles to the crank, and 90° behind it in the direction of revolution; so that the motion of the cylinder is in a direction contrary to that of the piston in the first half, and in the same direction in the last half, of the stroke. The breath of the annular opening is exactly equal

to that of the metal which separates the supply from the exhaust in the exterior cylinders; and it will be seen that the working cylinder itself performs the function of the slider in the valve box of the steam-engine. It happens accordingly that there is no interval between the shutting off of the supply and the commencement of the discharge; but that the efflux begins the moment the influx ceases.

It would be difficult to judge of the practical usefulness of a machine of novel character, from the imperfect opportunities which are afforded to study its working in a place like the Exposition. Fortunately, however, this particular engine has been made a subject of very elaborate theoretic discussion and experimental study by a very competent critic, M. Ordinaire de Lacolonge, who has published an extended paper on the subject in the *Annales du Conservatoire des Arts et Métiers*, and whose conclusions in regard to it are summed up succinctly in the following propositions:

The performance of the machine is better at low than at high velocities of the piston.

When the motion of the piston is about one metre per second, the performance is equal to that of other good hydraulic motors; that is, it is above 60 per cent. of the hydraulic power expended.

The machine cannot be advantageously employed with water carrying sand.

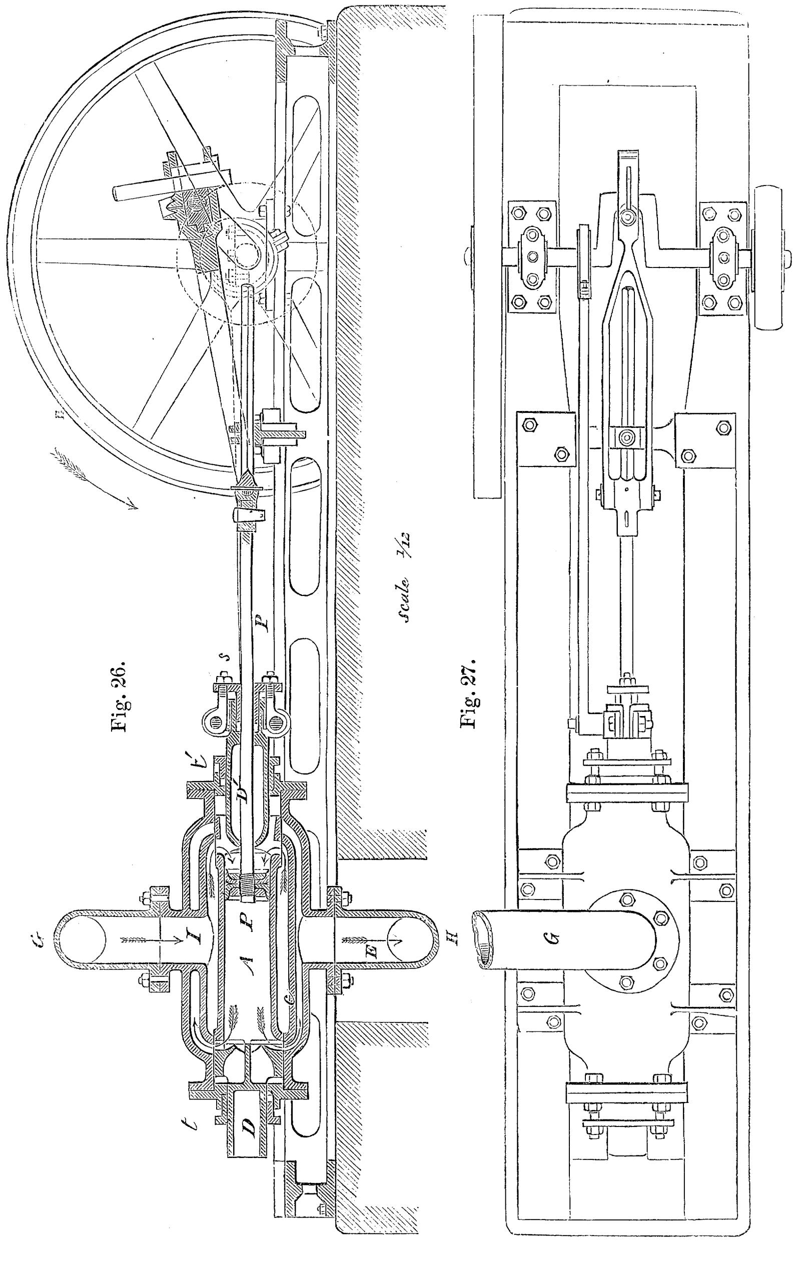
This water-engine is especially adapted to the utilization of small volumes of water having a large fall.

And it may be further added that the machine may be placed at a point intermediate between the source and the level of final discharge, with the full effect due to the total head, provided the discharge be through a tube continued to the lower level, and of such form that air shall not enter it from below.

Mr. Perret exhibited two of his motors in the Exposition, one of which was mounted as an oscillating engine. This form is exceptionable on account of the large lateral friction which it introduces between the external and internal cylinders. The other was employed to drive a rock-perforator, the invention of Mr. De la Roche Tolay, a French engineer, which itself excited a good deal of interest, being the machine known as the "diamond perforator." In this machine the perforating tool consists of a soft iron ring fitted to the extremity of a steel tube from which it may be removed at pleasure, and carrying eight black diamonds firmly set in its circumference. These eight diamonds are set alternately on the inner and outer edges of the face of the ring which is presented to the rock. The mineral called here black diamond, is essentially the same thing as the transparent gem of the same name, but is of greatly inferior value. It is found both crystallized and uncrystallized; but, for the purpose required in this operation, the uncrystallized form is preferred, as presenting no natural cleavages. The mineral is sold by weight, its cost being proportioned to the weight simply, and not to the

square of the weight, as is the case with the precious diamonds. The cost of a ring, such as is described above, is 175 francs, or $35.

The diamond perforator penetrates the rock, of course, by friction and not by percussion. It receives, therefore, from the motor a motion of



Perret's Water-engine.

rotation, being pressed in the meantime firmly against the rock by hydraulic pressure applied through a second independent cylinder and piston. The experiments which have been made with this perforator give results which promise important economical advantages from its use in rock-boring. Some of these results are as follows:

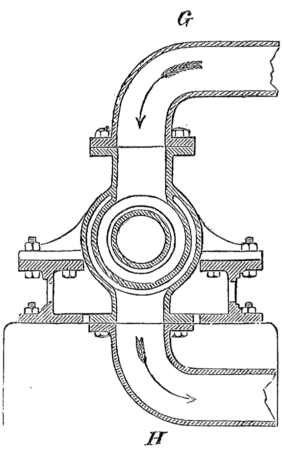
Under a pressure of eight atmospheres, 100 turns of the perforator per minute give: in old mica schist, containing little quartz, 1.2 inch; in similar rock, with much quartz, 0.4 inch to 0.6 inch; in quartz from the tunnel of Mont Cenis, 0.56 inch; in very hard dolomitic limestone 0.8 inch.

Under the same pressure, increasing the number of turns of the perforator from 100 to 250 per minute, the advance is very exactly twice and a half as great as before, showing that the effect is proportional to the velocity.

In order to produce a velocity of 100 rotations per minute, an expenditure of seventy-five litres, or about twenty gallons of water, was necessary in these experiments.

The inventors expect to be able to reduce the expense of rock-drilling seventy-five per cent. upon the present actual cost after the apparatus has been once set up. The application of the hydraulic motor would, however, be attended with only a moderate economy if it should be necessary to raise the water which is required to drive the engine by artificial means to a suitable level.

Fig. 28.



The construction of the engine, above described, will be understood from an examination of Figs. 26, 27, and 28:

A, (Fig. 26,) is the inner cylinder. B B mark the external cylinder, and C C the intermediate. P is the piston just beginning to descend. The arrows show the openings for entrance and discharge of water. I is the induction pipe, and E the eduction pipe. D D are prolongations of the working cylinder, in smaller diameter, to allow it to slide forward and backward. The piston rod *p* passes through a stuffing-box *s*, at the end of D′. There are also stuffing boxes at *t* and *t*′.

Fig. 27 is a view of the engine in plan, and Fig. 28 is a section through G H, in which the relation of the induction and eduction pipes to the external and intermediate cylinders is clearly shown.

COQUE'S WATER-ENGINE.

A third form of water-engine was exhibited by Mr. A. Coque, of Paris. This is also reciprocating, and its peculiarities consist in the operating of the induction and eduction valves by means of a cam on the working

shaft instead of an eccentric, in consequence of which arrangement the change is made abruptly at the end of the stroke; and in the admission of a small amount of air along with the water, by means of which the danger of a hydraulic concussion is obviated. This last feature is not without importance, as it removes one of the greatest difficulties in the way of the successful operation of water-engines.

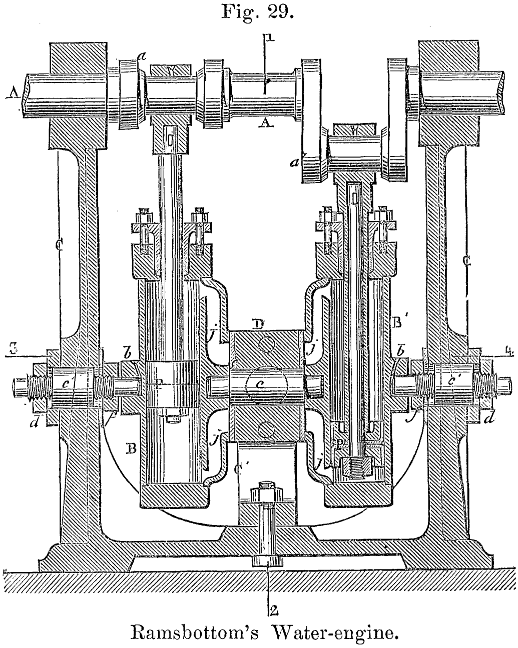
The inventor represents that, in case of a deficient supply of water, the quantity of air admitted may be increased; for which purpose he employs a second valve, capable of adjustment to the quantity required. In this case, the air, which is admitted before the water, is first compressed; and it afterwards reacts by its own elasticity, so that the engine has to some extent the double character of a water and of an air engine.

The machine exhibited is in dimensions hardly more than a model, the diameter of its cylinder internally being only thirty-one millimetres, or an inch and a quarter, and the length of stroke 162 millimetres, or six and a half inches. Its performance yields about sixty-four per cent. of the power applied. Under a pressure of twelve metres of water (nearly an atmosphere and a quarter) and with sixty revolutions per minute, it furnishes actually about one-eighth of one-horse power. On a larger scale the result might probably be still more satisfactory.

RAMSBOTTOM'S WATER-ENGINE.

None of the water-engines exhibited seem to possess the merit of those of Messrs. Ramsbottom & Co., of Lancashire, England, which are so extensively in use in the British foundries; and some surprise was felt that these engines were not repreented in the Exposition. The following brief description of one of the Ramsbottom engines is here introduced for the purpose of comparison:

Fig. 29.

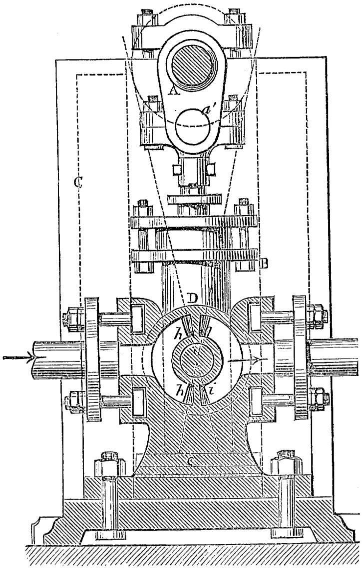


Ramsbottom's Water-engine.

The engine is oscillating, and employs two cylinders operating the same working shaft by means of two cranks at right angles to each other. The cylinders are supported in a stout framework of cast-iron. The details of construction may be best understood by reference to the accompanying figures. Fig. 29 is a section through the cylinders, which are

vertical, and shows the mode of suspension of the cylinders, and the channels of induction and eduction, which are marked *j*, and which are cast with the cylinder. The dotted circle *c* shows the position of the supply and discharge pipes. Fig. 31 shows a cross-section of the cylinders and their pivots, and in this will be seen the places of attachment of the pipes just mentioned at K and K. The pivots are of steel. Those intermediate between the cylinders are firmly fixed in the support. The external pivots admit of adjustment by means of the screws and screw-nuts *d* and *f*. Fig. 30, which is a section through the line 1 and 2, Fig. 29, shows the system of water distribution. The apertures of induction and eduction are represented at *h* and *i*, and have the form of truncated circular sectors, whose centre is the centre of motion. The spaces marked *h* are divided from those marked *i* by a sectoral partition, which is of precisely the same area in cross-section as they. The apertures of admission and discharge on the side of the cylinders are also of the same form and dimensions. The surfaces of contact between the cylinders and the support D are perfectly plane and polished, and are made water-tight by means of the adjusting screws *d* and *f* of the pivots. When the piston is at the end of its course in either direction, the cylinder will be truly vertical. In this position the piston is momentarily at rest, and both induction and eduction valves should be closed. Accordingly the disposition of the parts is such that, when the cylinder is vertical, the openings by which the channels *j j* communicate with the supply and discharge pipes present themselves exactly opposite to the solid sector dividing *h* from *i*. In the next moment the flow of water will recommence, the cylinder discharging itself from the full side of the piston, and filling anew on the opposite side.

Fig. 30.



Ramsbottom's Water-engine.

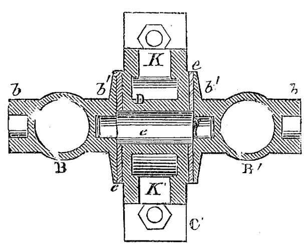


Fig. 31.

From this statement it is apparent that the influx and efflux of the water proceeds with more and more freedom from the beginning to the middle of the stroke, when the passages are at their maximum opening, and that from this point to the end the reverse takes place. But it is to be also observed that, from the nature of crank-motion, the velocity of

the piston varies correspondingly, and that the relation of the supply of water to the demand is very nearly constant.

Very nice adjustment is evidently necessary in these engines, in order that the moment of the absolute closing of the valves may correspond to that of the completion of the stroke; and as it is possible that this perfect coincidence may not be exactly secured or permanently maintained, some provision against counter-pressure and the effects of hydraulic shocks is necessary. Air chambers and relief valves are employed for this purpose. The relief valves open a backward communication between the cylinder and the driving column, so that if there occurs an obstruction to the discharge, the pressure on the two sides of the piston will be equilibrated by the opening of the valve.

The engines constructed by Messrs. Ramsbottom on this model are generally small, some of them having cylinders of not more than two inches in diameter. They have been used for a variety of industrial purposes, as for operating printing presses, circular saws, lathes, &c., as well as for cranes and other machinery in foundries. Their simplicity and neatness render them preferable to almost any other form of small motor, wherever the hydraulic head can be easily secured for working them. But in general it is not a natural hydraulic head that is depended on, and indeed no natural head could furnish, in machines of so small model as those employed in the British foundries, anything like the large power which they exert. The head is established in an *accumulator* of power, which is a body of water driven into a reservoir under heavy pressure, by forcing pumps worked by steam. For lighter industries such expedients are unnecessary. In cities in which the water distribution is from elevated reservoirs, and in which the water supply is sufficiently abundant to justify the application of a portion of it to industrial uses, the water-engine is recommended by the combined advantages of simplicity, neatness, compactness, constant readiness for work, perfect safety, economy while working, and the absolute cessation of expenditure during interruptions and after the work of the day is over.

WATER-WHEELS AND TURBINES.

One of the most striking objects in the section of the park allotted to France in the Exposition, was a model of one of the six great water-wheels constructed at Marly by order of the Emperor for the purpose of driving the water-works which supply the city and palace of Versailles. These wheels are twelve metres (about forty feet) in diameter, constructed of iron, with plane wooden floats. They present no novelty in principle, but are magnificent specimens of workmanship. The only water-wheels exhibited which embraced any novelty were those of Mr. Delnest, of Mons, and of Mr. Sagebien, of Amiens.

The wheel of Mr. Delnest has great breadth compared with its diameter, and is provided with floats called helicoidal. These are in fact

nearly plane, but are slightly winding, screw-shaped, upon the cylindrical body of the wheel, so that the two opposite ends form contrary screws which meet in the middle line at an obtuse angle. As the wheel turns, the angle meets the water first, and according to the inventor the inclination of the two sides facilitates the escape of air. No experimental results of the performance of this wheel were given.

The other wheel mentioned, that of Mr. Sagebien, which is designed as a kind of breast wheel, is provided with plane floats, very deep relatively to the wheel, (about one-third of the radius,) and inclined so as to enter the water by their outer edges first. After the immersion of the edge, therefore, there will be an enclosed space between the float and the cylindrical surface of the wheel which, unless the velocity of rotation were very slow, would be liable to retain a certain amount of air. This velocity is, however, designedly kept low, and a large diameter is given to the wheel, by which means the water, acting by its weight upon a long radius, imparts great power and expends nearly all the work that is in it in making the descent. The wheel works very near to the walls enclosing it, and the waste by escape is not considerable. The actual velocity at the circumference is but about two feet or two and a half per second, while the entire circumference is from seventy-five to one hundred feet, so that it turns hardly more than three times in two minutes. It is to be said in favor of this wheel that it economizes the driving power to a remarkable degree, yielding not less than seventy per cent. of the total. On the other hand, its revolution is so slow that for most purposes it is necessary to employ accelerating wheel work to a greater extent than is required by most motors, so that the economy is partially balanced by increase of friction, greater complication of machinery, larger cost for the original constructions and occasional repairs, and correspondingly increased liability to derangement.

Mr. Colladon, of Geneva, exhibited in the Swiss department a wheel adapted for use on streams whose natural current furnishes a sufficient power to be made available without a dam, and which also are liable to considerable changes of level. This is called a floating wheel, from the fact that the construction permits it to follow the elevations and depressions of the water as occasion may require. Although the wheel is thus movable, the machinery which it moves is fixed; and the peculiarity consists only in the connections which permit the transmission of the power in all the changes of its position. It is an expedient which in certain situations may be useful as being the only one available, though not suited to furnish a very large amount of power, nor that, in theory, very economically.

The hydraulic motors which in general furnish the largest useful effect in proportion to the living force of the water which passes through them, are the class called turbines. The theory of the turbine was ably investigated by Euler, but its practical realization was not accomplished until 1832, which is the date of the invention of the motor known as the "tur-

bine Fourneyron." Euler's idea was to construct a horizontal wheel to turn on a vertical axis, and to be driven by water directed from a reservoir immediately over it, upon floats of curved form fixed to its circumference. The curvature to be given to the floats was such, that at the top, where the impulse of the water was to be first received, they should be nearly vertical, while at the bottom they should approach the horizontal. Within the reservoir he proposed to place a set of curved plates to give direction to the issuing water, in which the construction above described should be reversed, the summits of the *directrices* being nearly vertical, and their lower edges nearly horizontal. By this arrangement it would happen that the water at its first discharge would strike the faces of the floats or pallets nearly in the plane of rotation; and before its final escape, it would transfer to the wheel nearly all its living force. No water from the reservoir was to be admitted to the wheel except that which was directed on the pallets.

FOURNEYRON'S TURBINE.

The Fourneyron turbine was a departure from Euler's plan, but it was conformed to the general principles of his theory. The water from the source was admitted into a cylinder of small diameter, closed at the bottom. In the middle of this cylinder was fixed a still smaller one, through which the axis of the turbine ascended, being thus protected from contact with the water which was confined to the annular space between the two. The turbine itself was a horizontal disk running close to the bottom of the cylindrical reservoir, but larger in diameter; its floats being fixed to the perimeter of its upper surface, and forming a ring which surrounded the bottom of the reservoir. The apertures for the efflux of the water were therefore placed in the cylindrical surface of the reservoir, opposite to the floats, and the escape was as nearly as possible tangential to this surface. The manner of opening and closing these apertures of escape was by means of an interior cylinder accurately fitting the main cylinder of the reservoir, and this was lifted and shut down by mechanical contrivances operated by the attendant from above. Other turbines, more nearly on the plan of Euler, have since, to a great extent, superseded the turbine of Mr. Fourneyron. To understand their peculiarities, and to be able to judge of their respective merits, it is necessary to attend to two or three preliminary considerations.

A turbine wheel will run though entirely immersed in the water; but it will perform best if kept free from contact with all water except that which is employed in propelling it.

As the supply of water varies, or as the work which the wheel is required to do is greater or less, it is desirable to enlarge or diminish the amount of water admitted to the wheel. There is of course a certain maximum amount which cannot be exceeded, and this will be the amount received by the wheel when all the orifices of discharge are fully open. This maximum may be reduced in either of two ways: First, the size of

each one of the apertures of discharge may be partially reduced; a result which may be obtained in the Fourneyron turbine by depressing more or less the internal cylinder which forms, as above stated, the *gate;* or, secondly, a larger or smaller number of the openings may be entirely closed while the remainder are left open to their full extent. The first of these methods was employed by Mr. Fourneyron, but experience has proved that it is disadvantageous. The floats are not filled, and the water escapes without having fully expended its force against them. In order to meet this difficulty, Mr. Fourneyron divided the water space between the floats by means of horizontal partitions, so as to form three sets of cells having the relative capacities, one, two, and three. This allowed the gate to be raised to three different heights, but did not provide for intermediate elevations; and it increased also the proportional amount of frictional surface. In the more recently constructed turbines the problem has been resolved in a more general manner.

In order to secure the largest benefit from the given fall of water, it is desirable to place the turbine as low as possible. This is inconsistent with the condition of best performance mentioned above, which requires that it should not be immersed, unless at least some means can be contrived by which it may be made to run in air, although beneath the surface of the water at the foot of the fall.

THE GIRARD FREE TURBINE.

The most striking improvement which has been made in connection with the turbine wheel since the earliest industrial application of the machine by Mr. Fourneyron, is one by which the important object just mentioned has been effectually secured, and is due to Mr. Girard, of Paris, who has also in many other ways perfected this important machine. This consists in adapting to the lower part of the water cylinder an air chamber, open at the bottom, which encloses the wheel, and from which the water is excluded, whatever may be the level in the natural channel without, by condensing the contained air to a suitable degree of elasticity. For this purpose a small air-pump, worked by the machine itself, is employed to throw air into the chamber in order to supply the loss which may occur by leakage, which is inconsiderable. The level of the water is thus kept constantly below the lower extremities of the floats of the wheel, whatever may be the changes of natural level. To prevent the loss which might arise in consequence of the entanglement of bubbles of air in the water escaping from the wheel, an expedient is adopted which is at once ingenious and effectual. The water which escapes, instead of being left free to mingle at once with that of the stream below, is kept confined within an inverted trough for a sufficient distance to allow the air which is mechanically mingled with it to rise to the top, when it is received into a bell-shaped chamber, which arrests its further progress. A tube connecting this chamber with that enclosing the wheel, returns it by the mere effect of hydrostatic pressure.

THE FONTAINE TURBINE.

Turbines on the plan of Euler were first introduced by Mr. Fontaine, of Chartres. Examples of the Fontaine turbines were exhibited by Messrs. Brault and Berouard, also of Chartres. In the original construction of Mr. Fontaine the water was admitted to the floats of the wheel by a system of small sliding gates or valves, each opening being provided with a separate gate, but the whole being raised and depressed together. The wheel itself was immediately and entirely under the cylindrical water chamber; its extreme diameter, from out to out, including the floats, being the same as that of the reservoir. The water openings formed therefore a ring arranged around the circumference of the water cylinder, and were pierced through its bottom, and not, as in the turbine of Fourneyron, through the sides. But as the form of the directrices was such as to be nearly vertical at top, and horizontal at bottom, the lower lip of each of the directing plates was almost vertically under the upper edge of the one next following; so that a valve sliding vertically could close the channel of discharge, without intersecting either of the bounding surfaces in such a manner as to produce any obstruction to the water by irregularity of flow or increase of friction. As all these valves were raised and depressed together, the quantity of discharge could only be varied, as in the case of the turbine Fourneyron, by raising them partially or wholly, according to the exigency. But this method was attended with a disadvantage similar to that indicated in the former case. The action of the water on the floats was not favorable unless they were fully filled. In the case of the Fourneyron turbine, when the water was but partially turned on, it was received on but a part of the breadth of the float; in the present case it was received on the entire breadth, but in a thinner sheet. The effect, however, was practically the same; to which it may be added, that the frictional resistance opposed to the issuing water in the Fontaine turbine, when the valves were but partially opened, was considerably greater in proportion to the whole force than when the passages were entirely free.

TURBINES OF BRAULT & BETHOUARD.

The more recent improvements of the turbine have been concerned mainly with the construction of these valves. Vertical sliding valves have been generally abandoned. In the turbines of Messrs. Brault & Bethouard, the valves are simply covers formed of gutta-percha, strengthened by metal plates, each of sufficient size to close one orifice. These valves are connected together in a manner to facilitate the control of them, and are in two separate sets. The mode of control will be understood by considering that the orifices to be closed form a regular ring. If we cut a ring of the same figure out of paper, and, laying it flat upon a table, place upon it a cone, with the vertex truly at the centre of the ring, and then cutting the paper in the direction of the radius, attach

one of the cut ends to the surface of the cone by means of some adhesive substance, we shall be able, by merely rolling the cone on the table, to take up the entire ring, and by reversing the direction of the rolling, to lay it down again; the vertex of the cone in the meantime maintaining its position at the centre where we originally placed it. This is the expedient adopted for opening and closing the water passages in the turbines here spoken of, only that two cones are employed instead of one. It is only necessary to suppose in the illustration just given, that to the surface of the ring of paper there are pasted a number of fan-shaped bits of stiff card-board, all equal to each other, and we shall have a representation of the valve system of Messrs. Brault & Bethouard. It is only necessary to add that the end of the ring not secured to the cone must be fixed to the interior of the water chamber. This system, it will be seen, will allow the quantity of water admitted to the wheel to be increased or diminished at pleasure, while all the orifices which are opened at all are opened entirely. It has been mentioned that there are two cones employed in the manner described. This is partly in order to direct the action of the water symmetrically on the circumference of the wheel, and partly because in this form the apparatus is neater. A single cone for the whole circle would moreover require to be larger, and would, therefore, interfere to a greater degree with the access of the water to the openings which happen to be near it, a disadvantage which is to some extent true of the actual construction. Another disadvantage of this construction is, that in case foreign substances are brought along by the water and lodge in the passages, the valves fail to shut closely, and water is lost by leakage.

In several other turbines exhibited the valves were constructed with hinges, and the mechanism controlling them was designed with a view to vary at pleasure the number open. These answer perfectly the purpose intended when the water is entirely clear, but they are liable to the objection in regard to obstruction which has been made to the system last described.

PROTTE'S TURBINES.

Mr. Protte, of Vendeuvre, (France,) exhibited one turbine in which all the orifices of discharge in an entire semicircle are closed by one flat sliding cover in the form of a ring. By giving to this ring a sliding motion, having as its centre the centre of the reservoir itself, a larger or smaller number of the orifices of discharge can be opened at pleasure. It is apparent, however, that if, as in the ordinary construction, the whole circumference of the water chamber were occupied by these orifices, it would be impossible to uncover, by means of such a sliding semicircle, one aperture, without closing another. Mr. Protte endeavors to get rid of this disadvantage by placing the discharge orifices of one-half of the circle nearer to the centre than those of the other half. He has, therefore, a second semicircular cover, which is a portion of a ring

of less diameter than the first. By means of these two, all the openings can be controlled, and a greater or smaller number uncovered at pleasure. It follows, of course, that the directrices of the water corresponding to the second set of openings just mentioned, must be so constructed as to convey the water to some extent in a radial as well as in a lateral direction. In the changes of direction and increase of friction thus introduced, there is some disadvantage, but the system of water control is undoubtedly preferable to any of those previously described.

GIRARD'S IMPROVED TURBINE.

Mr. Girard has constructed turbines designed to admit the water only on two opposed quadrants of the circumference. In these, the system of sliding valves just described (which was first introduced by him) admits of being used, without being liable to the objection pointed out as attending that; since each annular valve cover, being but ninety degrees in extent, may be turned entirely off from the group of openings to which it belongs, without encroaching on those of the opposite group.

Another method employed by Mr. Girard to secure effectually the control of the discharge of the water, and at the same time to utilize the whole circumference of the wheel, is to close the apertures of discharge by slides which move outwardly in a radial direction. But, inasmuch as there is always liability to obstruction, from the intrusion of the debris of vegetation or other matters borne along by the stream, when the apertures are small, he prefers in many cases to admit the water only to a part of the circumference, a third for example, or a fifth, and to leave all the rest of the wheel uncovered; which construction allows access to the floats, permits obstructions to be removed without difficulty, and greatly facilitates the execution of any necessary repairs. As a compensation for the smaller number of floats acted upon, he makes the apertures larger, and increases the diameter of the turbine at the same time. These machines are called by him "lateral-injection turbines."

RIETER'S TURBINE.

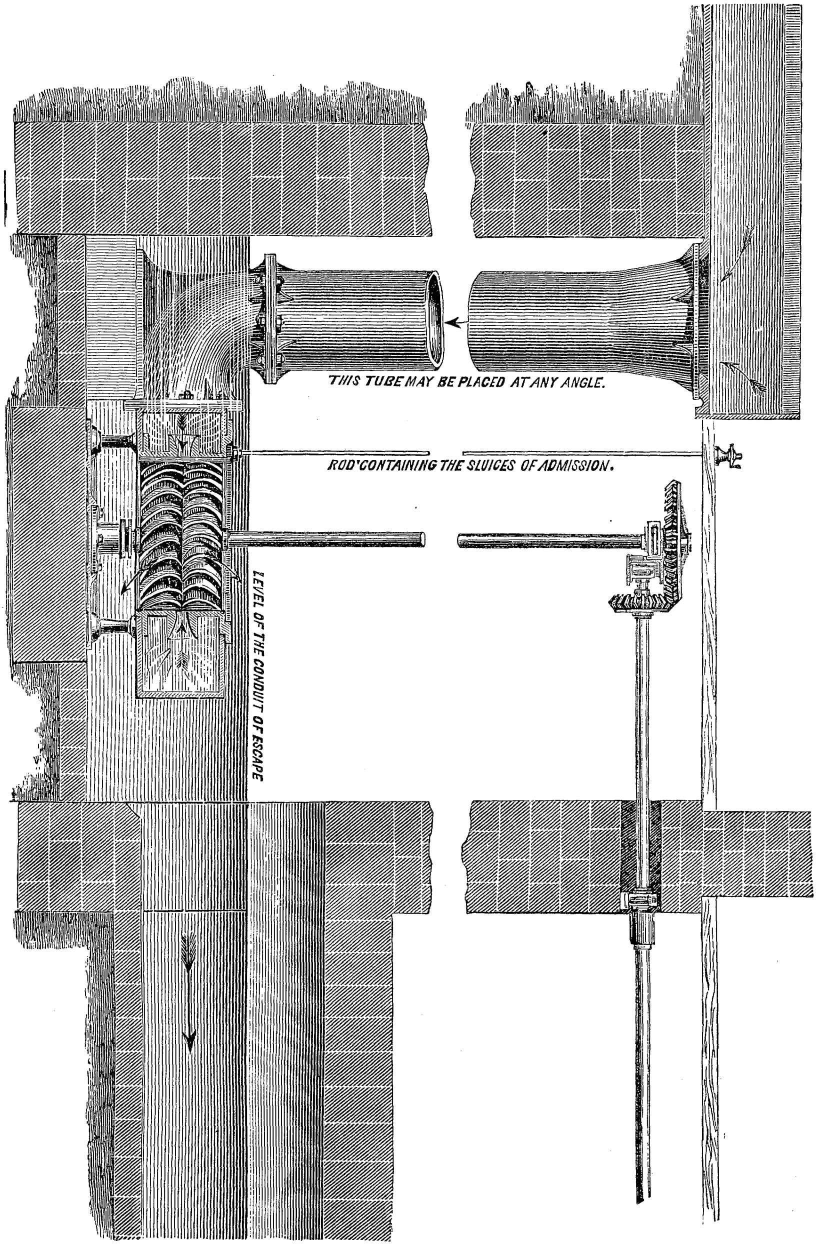
Several other lateral injection turbines were on exhibition. One of these, by Mr. Rieter, of Switzerland, was without any system of directrices. The tube which conducted the water to its circumference formed a kind of box embracing only about a quarter of a circle, the remainder of the wheel being free. It was said to give a return of seventy per cent. of the force applied.

SCHIELE'S TURBINE.

Another, exhibited by the North Moor Foundry Company of England, the invention of Mr. Schiele, possesses the great merit of extreme simplicity of construction, of entire accessibility at all times, and of utilizing as

large a proportion of the power as the best Fourneyron or Girard turbine. This also is a lateral injection turbine, and requires no other

Fig. 32.

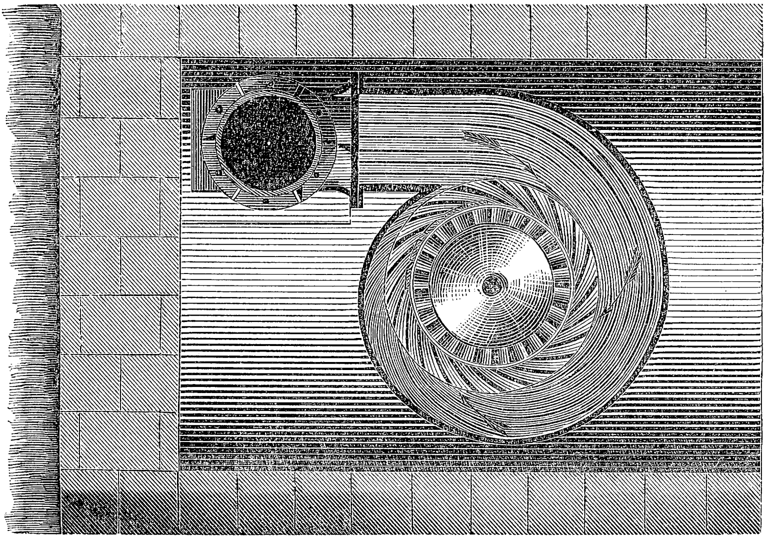


Schiele's Turbine.

directrix for the water but the tube of supply. Its construction will be understood by referring to the figures. It is enclosed in a cylindrical box which is open both above and below, and which serves only to guide the

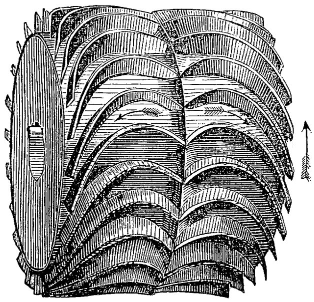
water as it enters by the lateral pipe shown in Fig. 32 in elevation, and in Fig. 33 in plan. The construction of the wheel itself is seen in Fig. 34.

Fig. 33.



Schiele's Turbine—plan.

Fig. 34.



The floats have such a form as may allow the water to expend its force in giving rotary motion to the wheel, and finally to escape in a direction up or down nearly parallel to the axis.

The figures represent the Schiele turbine as placed in the ordinary position with the axis vertical. But it works equally well with the axis in a horizontal position; a fact not equally true of ordinary turbines. This, however, is often a great advantage in the application of power; permitting such an arrangement as may make the application direct, whatever may be the nature of the work to be done. Another great advantage is that it may be placed at any level between the head and foot of the fall, and yet make available the force due to the entire head. In order to do this, however, the wheel must, of course, be wholly enclosed, and the water which leaves it must be conducted down to the lowest level in a continuous tube, where it must either be recurved to prevent the admission of air, or, what is better, be immersed in the water of the stream below. Under these circumstances it acts by its weight on the wheel, precisely as, supposing the top of the tube to be closed by a piston, and the water above the wheel to be without weight, this water below would still drag down the piston with the same force with which it would press it if it were

introduced above. Some of the turbines of this company have been established at points thirty feet above the foot of the fall by which they are driven. This is an important advantage in respect to the application of force, and may often serve to render complicated systems of transmission unnecessary.

It should be mentioned, however, that the ordinary turbine is capable of being employed in the same manner, at a point chosen at pleasure between the highest and lowest level. The construction adapted to this mode of employment is commonly called the Jouval turbine; but it has no peculiarity to distinguish it generically from the turbine of Fontaine. The wheel is simply enclosed hermetically, and a tube is continued, as above described, to the lowest level.

THOMPSON'S TURBINE.

An additional form of the turbine was exhibited by Messrs. Williamson, Brothers, of Kendal, England, the invention of Mr. Thompson, of Glasgow. The peculiarity of this consisted in the admission of the water horizontally at the circumference of the wheel, and permitting it to escape, after having expended its force, at the axis. This is what may perhaps be called the Fourneyron turbine inverted. The floats or pallets of this wheel are proportionally longer, measured in the radial direction, than those of the turbines constructed on the principle of Euler, and they have a contrary flexure towards the centre. It is a disadvantage of this mode of applying the power, that the wheel cannot be enclosed in an air chamber according to the plan of Mr. Girard, but must necessarily be always immersed. The construction has also been criticised, on the ground that the centrifugal force which will be imparted to the water by the rotation of the machine will act in direct opposition to the driving column, and will to that extent neutralize its power. But it is to be considered, on the other hand, that the pressure thus seemingly lost is expended in forcing the rotating water nearer to the centre of the wheel, where its angular velocity is greater than that of the pallets, and where consequently it transfers its moment of rotation almost wholly to the wheel. Whatever amount of rotary motion is given by the wheel itself to the water is of course lost entirely in the ordinary turbine. If this can be by any contrivance retransferred again to the wheel, a compensation will be effected. The fact that the resistance opposed by the centrifugal force of water revolving within a wheel to the pressure of the propelling column is not a source of loss when the pressure drives the revolving water to the centre, is practically demonstrated in the hydraulic machine called the *danaid*, invented by d'Ectot.

THE DANAID.

The *danaid* may be described as being formed of two hollow cylinders placed concentrically one within the other, and enclosing a small space between them. The inner cylinder is closed at the bottom; the outer has

an aperture in the bottom at the centre. Between the two bottoms there is a space of an inch or two, in which are placed a number of partitions extending from the central aperture to the circumference, which prevent the possibility of a rotation of the vessel without carrying along with it any liquid which may be between them. But the annular cylindrical space is without partitions. The contrivance being placed in a vertical position, and sustained by an axis permitting free revolution, water is introduced into the annular cavity through one or more pipes proceeding from an elevated reservoir, and directed, at the orifice of discharge, as nearly tangentially as possible to the cylindrical surface. Rotary motion is imparted thus at first to the machine by mere friction; but as the velocity increases, the centrifugal force tends to resist the discharge at the central orifice. The pressure of the column, however, prevails over centrifugal force, and the rotating water is driven constantly toward the point of discharge, imparting of necessity the living force which it had acquired by revolution to the vessel itself, by pressing laterally against the partitions.

In a series of experiments made in 1813 by Messrs. Prony and Carnot, of the French Institute, on the *danaid* of Mr. d'Ectot, it was shown that the work done amounted to seventy per cent., and sometimes to nearly seventy-five per cent., of the power due to the hydraulic head. Yet here it is evident that, but for the rotary motion given to the water, and the consequent resistance opposed to the head by centrifugal force, the performance would be trivial. The friction of the inflowing water on the smooth cylindrical surfaces of metal (the machine was made of tin) would furnish but an insignificant propelling power. Moreover, the partitions in the circular space between the bottoms are entirely essential to the performance of the machine.

The Thompson turbine, therefore, is liable to no theoretic objection upon the score that it receives the water by the circumference to discharge it by the centre. It is only important that the cylindrical section of the interior of the wheel should be enlarged relatively to that of the circumference, to correspond to the diminution of radial velocity which takes place toward the openings for discharge.

GIRARD'S HYDRAULIC PIVOT.

Before leaving the subject of turbines, one very important and ingenious invention of Mr. Girard, tending greatly to reduce the wear and tear upon a point which is especially liable to suffer, while its failure is a misfortune of the most serious gravity, must not be overlooked. The pivot on which the axis of the wheel rests bears the whole weight of the wheel and shaft, and to some extent that of the escaping water. From the very rapid rotation there is great liability to wear away by friction. Mr. Girard's invention is one by which this friction is made almost wholly to disappear, an effect which is produced by what he calls his hydraulic pivot. The principle of this contrivance will be understood by compar-

ing it to the piece of apparatus commonly called the hydraulic bellows, used to illustrate the hydrostatic paradox. Or it may be compared to an ordinary hydrostatic press, in which a very small force may counterbalance a great one.

To the bottom of the revolving shaft is firmly attached a horizontal circular plate of iron. To the support of the socket in which the shaft is pivoted is fixed another similar and equal plate. The two meet on their entire circumferences, and their surfaces are made so truly plane as to form a water-tight joint. But at a little distance within the circumferences, toward the centre, these plates have an annular cavity, or broad groove, cut into them in the lathe, which, when they are in contact, forms a perfectly closed chamber. It suffices that one only of them should be thus indented. A small perforation through the lower or fixed plate is connected with a tube which is carried upward to the hydraulic head, and is put into communication with the water of the source. The water descending the tube enters the annular chamber just described, and exerts an upward pressure proportioned to the area of the ring and the height of the head. The weight of the turbine, axis, &c., being known, it can easily be calculated what should be the size of the ring that the weight may be just balanced. The friction on the pivot will thus be reduced as nearly as possible to zero. If the hydraulic pressure slightly exceeds the weight it will be all the better, for, in that case, the opposed bearing surfaces will have a film of fluid interposed between them, which will prevent wear altogether. The amount of water escaping through so minute a fissure will at the same time be so small as to be quite inappreciable.

VI.—AERIAL MOTORS.

The atmosphere presents a source of motive power which, but for its large and capricious fluctuations, would be made much more generally subservient than it is in fact to the uses of the industrial arts. Though not suitable for impelling heavy machinery, its presence everywhere, which is always a recommendation, makes it in certain circumstances an invaluable auxiliary to the minor and especially to rural industries. There are many territories where water powers do not exist, and where motors driven by artificial heat are not economical except for large manufactures. In such situations the wind performs a service of inappreciable value in superseding the labor of men or animals. It is an objection to the windmill that it is often idle when its service is most wanted. For rural industries it will generally be practicable so to arrange work as to take advantage of the favorable seasons without being too much incommoded by the calms; but in case a motive power is required to be at all times available, the object may be secured by means of a windmill having, while in action under favorable circumstances, an excess of power, which may be used to accumulate a head of water for use in the intermediate intervals.

The practical problem of applying to use the motive power of the wind is complicated by the frequently changing direction of the wind itself. In most windmills the difficulty is met by making the part of the machinery which constitutes the motor proper rotatory around a vertical axis. This construction involves necessarily a weak point, and affords opportunity for the exercise of ingenuity in devising means for securing sufficient strength without greatly adding to the weight or increasing the friction of the moving parts. The two objects are to a certain extent incompatible; and it is probable that in general it is only the consideration of cheapness which determines the adoption of a form which had its origin in the infancy of mechanics.

There were exhibited in the Exposition four windmills in actual operation, and one in design. Of the four, three were French, and one was Belgian. The number of sails was different in the different machines, one having as many as twenty, the others sixteen, eight and six. The peculiarities of construction which deserve attention are those which concern the regulation of velocity under varying force of wind.

MAHOUDOU'S WINDMILL.

In the windmill of Mr. Mahoudou, of St. Epain, France, the sails, which were of canvas and six in number, were attached at the outer extremity of the arm to a yard possessing a certain degree of flexibility, but stiff enough to resist the ordinary pressure of the atmosphere, and to maintain the sail at a determinate angle of inclination. Under a higher degree of pressure, the springs, by yielding, reduce the amount of surface exposed to the wind, in proportion to the excess of pressure; and thus serve to maintain a tolerably uniform rate of rotation.

FORMIS'S WINDMILL.

A different contrivance for the same purpose was observed in the windmill exhibited by Mr. Formis, of Montpellier. In this machine the sails, which are of canvas, as in the one just described, are attached on one side to rigid arms; while they are stretched by yards attached by one end to the arms, at points about half way from the centre, and by the other to the free angles of the sails. From each of these free angles a cord is carried to the top of the next following arm, and thence, passing over a pulley, is continued down the arm to the axis of rotation, and through this axis, (which is hollow,) lengthwise, to the opposite extremity, where the whole system of cords is united, and by means of a suitable joint and lever is connected with a weight which acts as a governor. It is evident that when the pressure of the wind is sufficient to overcome the counterpoise, the sails will become more inclined, and will present a smaller extent of surface to the wind. The windmill of Mr. Formis was provided with eight sails.

THIRION'S WINDMILL.

A more important and more interesting machine of this class was pre-

sented, however, from Belgium, by Mr. Thirion. In this the sails are of wood and are from twelve to twenty in number. Each sail is hinged at two fixed points, one at the foot of the sail and at the axis of rotation, and the other at about half its length, where it is attached to a fixed circle, forming part of a framework by means of which the force is to be transmitted. Another circle, of the same size as this, and movable in guides, is attached to the centre of each sail through the medium of connecting rods. This circle, by its movement, affects simultaneously the inclination of all the sails. It may be set, in the beginning, at any inclination at pleasure; after which there can be, during the action of the machine, no diminution of the inclination; but in case the wind becomes violent the inclination will be increased by the effect of a centrifugal force governor acting on the movable circle.

While this contrivance has its merit, the most important and ingenious peculiarity of Mr. Thirion's windmill consists in a mode, which is certainly entirely original, of transmitting rotary motion between shafts which are not in the same direction, or in parallel directions, without the use of bevel gearing. It was not employed in the mill exhibited, but has been in use for a number of years in other mills by the same constructor. This ingenious invention is shown in the Figs. 35 and 36 annexed.

Fig. 35.

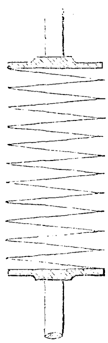
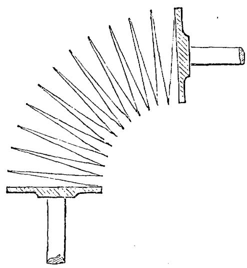


Fig. 36.



It is a spiral formed of a plane iron, or, rather, steel band, which is attached at its opposite ends to the two shafts to be connected. The diameter of the spiral will necessarily, in order to secure sufficient strength, be considerably larger than that of the shaft; and the attachment may be made by means of a cast-iron cap, having on one side a socket for the shaft and on the other a flat surface to receive the spiral. The breadth of the iron band or ribbon which forms the spiral is about an inch and a half, and its thickness a little more than a quarter of an inch. The total diameter of the spiral is about one foot.

Fig. 37.

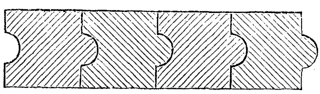
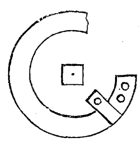


Fig. 38.



For a joint of transmission forming a right angle, about fifteen turns of the spiral will suffice. The entire spiral may be made of a single ribbon, or it may be made up, as it has been in some cases, of a number of parts connected together, as shown in Fig. 37, by tongue and groove. Experience has proved that this mode of transmission performs perfectly, without being liable to get out of order or to give

way. Its strength is very considerable, but cannot be indefinitely increased, since a thickness exceeding that which is adopted would bring too great a cross-strain on the metal. A number of these joints have been in operation without accident for several years. The mode of securing the spiral at its extremity is shown in Fig. 38. After the end has been riveted to the plate, a cross-bar is fastened below the rivets, so as to prevent a flexure at the point weakened by drilling. The windmill of Mr. Thirion, though self-adjusting to the wind, is not-provided with the ordinary wind-vane. In fact, the sails themselves fulfil the usual function of the vane, only that they are no longer, as in the ordinary construction, presented to the wind on the side of the tower from which the blast comes; but swing round, so to say, behind the tower. This part of the structure is therefore merely an open framework. The weight of the sails is balanced by a heavy counterpoise, and the whole rotating structure rests on balls, on a circular railway, resembling in this respect the dome of an astronomical observatory.

MOERATH'S WINDMILL.

The particular windmill which seems, however, to be the most decided improvement upon past forms of this motor, is that which was exhibited in designs by Mr. Moerath, of Vienna, which may be called an aerial turbine. This is shown in Plate V, Figs. 1, 2, 3, and 4, in which Fig. 2 is an elevation, showing the interior of a circular structure designed to enclose the wheel carrying the sails. The rotation is horizontal, the wheel turning round a central axis, shown at L. The form of the wings is exhibited in Fig. 4, which also shows in plan a series of fixed directrices, $a\,b$, $a'\,b'$, by which the currents of the air, coming in the direction indicated by the arrow, are deflected upon the sails of the windmill. This machine, therefore, resembles the turbine of Mr. Thompson, exhibited by Williamson & Co., the air entering by the circumference and escaping by the centre.

The sails are made of canvas, but their form is determined by the iron arms or frames to which they are attached. These frames are secured at top and bottom to two circular plates, which are fixed to the axis. Beneath the whole there is also attached to the axis a pulley which, by means of guide rollers, represented at K, (Figs. 2 and 3,) maintains it in position. The weight is sustained, and the level more truly preserved, by means of the rollers S, Fig. 3, themselves resting by their axes upon the smaller friction-rollers $s\,s'$. The guiding wheels K are sustained by brackets from the frame, shown at G in both figures. The power is applied through conical gearing, as shown at m or n, or in any other way.

The structure on which the motor rests may be of wood, brick or stone ; but the chamber in which the wheel is placed is designed to be constructed of iron, except the roof. Its base H forms a cast-iron crown, to which are bolted the brackets G, and from which rise vertically, at regular intervals, a series of rolled iron plates, which form the

directrices for the wind and also the support for the superstructure. It will be seen, by comparing the positions of the directrices in the plan with the directions of the arrows, that on the side on which the wind and wheel move in harmony, the wind can enter until its direction becomes tangential to the structure; while on the other side it is cut off from entering at all, by the overlapping of the borders of the directrices, up to the point where it becomes capable of such a deflection as to favor rotation. This wheel will, therefore, turn equally well, from whatever quarter the wind may blow.

The provision made for guarding against excessive velocity of movement in the case of high winds is ingenious. To every one of the directrices there is attached, on the outside, a shutter, wide enough to close entirely one of the openings, but pivoted by the middle points of its extremities, so that instead of closing one opening entirely, it closes the adjacent halves of the two between which it is placed. Thus, when all the shutters are closed, they meet each other half-way like the blinds of windows. In the plan, Pl. V, Fig. 4, these shutters are seen at $d\ c$, $d'\ c'$. In calm or in light winds they stand in the positions in which the figure represents them. But when the velocity of movement begins to rise above what is designed to be the limit, they are closed to a greater or less extent, by the effect of a self-acting apparatus represented in Fig. 2, and on an enlarged scale in Fig. 1, and through a system of connecting rods shown in Fig. 3. The main axis of rotation D carries a gear wheel r, which acts on the governor, Fig. 1, through the smaller wheel r', secured to the vertical axis of the governor. By the divergence of the arms of the governor the doubly conical friction wheel y is raised, and is brought at length to the point where its upper conical surface is in contact with the conical wheels Z and z. The wheel Z is fixed to its shaft and operates the conical gear wheels t. The wheel z is idle, its use being merely to equilibrate the pressure. The vertical conical wheel t turns the tangent screw f which rests on the perimeter of a large wheel, seen dotted in the plan of this part of the machine, Fig. 3. To this wheel x are attached a number of rods l, equal to the number of shutters; and these rods, by their opposite extremities, are fastened by hinge-joints to the outer extremities of the shutters, severally. An examination of the plan will show that if the wheel x be turned from right to left, the shutters will be drawn inward; and if the movement be sufficiently continued, they will be closed entirely. The action of the wheel Z upon the wheel x through the tangent screw, turns it from right to left; and thus by the automatic action of the machine itself the shutters are partially closed and the impelling force diminished. The velocity diminishing, the friction wheel y will descend, and Z will cease to act. If, in consequence of the reduction of the driving force, the retardation is in excess, the friction wheel y will descend until it comes into contact with Z' and z', of which the first is now idle, and the second turns the bevel wheels t', reversing the motion of the gear wheel x, and to a greater or

less extent re-opening the air passages. There may thus take place a succession of oscillations of the bevel wheel y, diminishing in extent if the breeze remains steady, until a permanent adjustment is attained. But if the wind varies, whether by an increase or a diminution of its mean velocity, the bevel wheel y will act anew and effect a new adjustment corresponding to the changed velocity. It is not to be understood that the wheel x will be acted upon in response to every momentary lull or gust, since the bevel wheel y has a sufficient freedom of movement between Z and Z′ to accommodate itself to these, so long as the average strength of the wind remains unchanged. But if there is a permanent increase or diminution of the wind force, the necessary correction will be made with infallible certainty.

The governor can be thrown out of gear with the machine; and if it is desired to leave the mill at rest, the wheel x, after detaching the governor, may be turned by hand so as to close the shutters entirely.

It is a great recommendation in favor of this motor, that it has no such weak point about it as has been mentioned as limiting the usefulness or impairing the strength of all the windmills in which the entire superstructure rotates around a vertical axis in order to present the sails to the wind. The present machine may possess all the strength of framework which it is possible to give to a turbine or water wheel.

It is also another and an important recommendation in its favor, that it is not liable to damage by the most violent storms; since, as we have seen, the effect of an increased strength of wind is to cause the shutters to close in proportion to the degree of the increase, so that when the violence is excessive they close almost altogether. Observations have been made of the action of mills of this construction which have been long in use; and the result is that the rotation is steady, and only slightly variable in rapidity, no matter how great may be the fluctuations of the wind. In the midst of the most furious gales, the work goes uniformly on, the wheel maintaining permanently the same mean velocity to which it was limited in the original adjustment of the governor.

There are large portions of our country in which the windmill is almost unknown. There are other portions, as in California, where they are extensively used and where objects of this class frequently strike the attention of the traveller. They would be undoubtedly much more generally introduced, if, in their ordinary forms, they were less rude and more efficient. They adapt themselves admirably to the circumstances of sparse settlements, in prairie districts and low alluvial regions, where streams are few and sluggish, where fuel is costly, and where the population, chiefly engaged in the cultivation of the soil, and living in comparative isolation from each other, find the conversion of their grains into flour and meal for domestic uses a serious tax upon both their time and their means. To such, the mills of Mr. Moerath, which are said not to be expensive, (the cost was not given,) would be extremely serviceable; while for many other light industries, such as the grinding of paints and

drugs, or the elevation of water for irrigation, for drainage, or for the ordinary uses of life, they are perfectly well adapted, and are probably in point of economy as cheap as any description of motor which could be provided for the same work.

VII.—ELECTRO-MAGNETIC ENGINES.

Several machines operated by the power of electro-magnetism made their appearance in the Exposition. Without counting the considerable number designed for purposes of demonstration, or intended only to serve as philosophic toys, there were present a number which had been constructed with a serious industrial object. It has been long since generally considered as settled, that motive power can only be obtained by means of electro-magnetic combinations at an expense which forbids the employment of such a power upon a large scale; but for many minor purposes in which the consideration of cost is unimportant, the convenience of application of this power has secured for it an acceptance which is becoming every year more general. The extensive introduction into families of the sewing machine has created a special demand for small powers; and it is here that the electro-magnetic engine finds a field of usefulness to which it is peculiarly adapted.

CAZAL'S ELECTRO-MAGNETIC ENGINE.

One of the machines presented in the Exposition, the invention of Mr. J. H. Cazal, of Paris, is expressly designed for this purpose, and has received from the jury the distinction of an honorable mention.

This is exceedingly compact, and as it takes the place and has the appearance of the fly-wheel of the common machine, it adds nothing to the weight or to the seeming complication. It is formed of a thick disk of soft iron, cut into the shape of a gear-wheel; a deep groove being afterwards cut down in the middle of the circumference, which is wound with insulated wire. The ends of the wire are soldered to insulated thimbles, which, by means of tangent-springs, introduce the battery current in the usual way. Surrounding this magnetic wheel is a heavy iron ring insulated on its interior surface in a manner to present elevations corresponding to the teeth or salient points of the wheel. This ring is fixed and the whole apparatus is more or less concealed by a neat annular metallic envelope. When the teeth of the wheel pass before the prominent parts of the surrounding ring, there is a near approach to contact, and the attraction is strong. When these teeth are half-way between those points, the opposite attractions are balanced. At the moment of nearest approach the current is arrested; it is renewed again at the intermediate position. In the interval, while the current is not flowing, the magnetic wheel maintains the motion in the manner of a fly-wheel.

BIRMINGHAM COMPANY'S ELECTRO-MAGNETIC ENGINE.

Another motor of this class is exposed in the British section by the Electro-Magnetic Company of Birmingham. In none of the electro-magnetic machines produced of late years does there seem to be much of originality. In fact there does not appear to be room for much. The efforts of inventors are bounded, and must be so, to the endeavor, by varying the combinations of the parts, to secure the largest amount of motion with the smallest differences of distance between the attracting or repelling poles.

The engine of the Birmingham company has four sets of fixed electro-magnets of the U or horse-shoe form, two sets at each end of an oscillating beam by which the power is to be utilized. The magnets of each set are arranged in two tiers, one above the other. The armatures of these several magnets are carried by rods depending from the ends of the beam; but the rods pass freely through these armatures without being fastened to them. When, therefore, an armature, in the descent of the rod, comes into contact with the magnet to which it belongs, the rod continues its motion and leaves the armature resting there. In the return motion the rod lifts the armature again, by means of a collar or enlargement which has been given to it at the place intended. Each armature has thus its collar, and these several collars have been so fixed upon the suspended rods, that the armatures reach the faces of their respective magnets successively, and no two at the same time.

In the action of the machine, the battery current actuates the magnets on the side of the descent; while on the other side the current is cut off. The machine acts therefore only by attraction. The armatures are of soft iron. As these armatures approach their magnets successively, it will happen that whenever one becomes inefficient, by coming into contact with its magnet, the next will be in position to exert a very high attractive force. And this force increases until this next makes contact with its magnet in like manner. On the whole it may be said of this machine that it presents what may be called a judicious arrangement of parts, but contains nothing which is new and nothing which can properly be called ingenious.

KRAVOGL'S ELECTRO-MAGNETIC ENGINE.

In the Austrian section appeared an electro-motor by Kravogl, which by its compactness, and by the great energy which it seemed to manifest within small space, excited much interest, but the construction was totally, and it might be said ingeniously, concealed; and neither the exhibitor nor any representative of his was present to give any information in regard to it. On attaching the battery it was instantly set in

motion, but this fact was the only evidence presented of the character of the machine, since no electro-magnet was visible.[1]

[1] Since this report was written, the following description of the machine above mentioned has appeared in a report on the electro-dynamic apparatus of the Exposition, made by Robert Sabine, Esq., of the British Commission :

"A new construction of electro-motor is shown by M. Kravogl, of Innsbruck, in which a hollow heavy wrought-iron wheel is rotated by means of a permanent magnet creeping up inside it. In principle the apparatus resembles exactly a tread-mill. Inside the outer case of iron in the centre of the section is a circular tube of brass, and in the annular space between the two tubes three coils of insulated wire are wound at right angles to the tangents of the periphery and connected with contacts properly placed at the axis. Inside the interior brass tube or ring is a magnet carried on anti-friction wheels, and occupying, perhaps, one-third of the whole circle. When a current is sent through the wire surrounding the magnet, the latter is deflected, or creeps up the ring on one side or the other according to the direction of the current, and by doing so displaces the centre of gravity of the whole system towards that side. In consequence the wheel must turn slightly on its axis to compensate this displacement. But while it does so the magnet creeps up still further, so that the wheel acquires a continuous rotatory motion. There is very little friction in this machine, and it is probably one of those in which the equivalent of mechanical force, gained by an expenditure of an unit of current, would be found the highest. This is not saying much, however, for in the best constructed machine this found value must fall far short of the theoretical equivalent."

From this statement it appears that whatever may be the coefficient of effective force in Mr. Kravogl's machine, the absolute amount of work which it is capable of performing must always be extremely limited; since at maximum it cannot exceed the weight of the magnet lifted through a space equal to that described by a point in the periphery of the wheel taken at the mean distance of the magnet from the centre of motion. In the machine exhibited, the magnet, though of course concealed from observation, could not, from the visible dimensions of the apparatus, have exceeded a pound or two in weight. To construct a machine on this principle, of any considerable power, it would be necessary very greatly to enlarge these dimensions.

CHAPTER III.

TRANSMISSION OF FORCE.

IMPORTANCE OF THE PROBLEM—LOSS USUALLY INCURRED IN TRANSMISSION—EXAMPLE OF HUELGOAT—AT NIAGARA—HIRN'S TELODYNAMIC CABLE—DIFFICULTIES ENCOUNTERED BY THE INVENTOR—HOW EXTENSIVELY INTRODUCED—PERCENTAGE OF POWER DELIVERED—COMPARISON WITH COMMON MODES OF TRANSMISSION—CALLES'S HYDRO-AERO-DYNAMIC WHEEL—IN WHAT RESPECT ORIGINAL—MECHANICAL PRINCIPLE INVOLVED—INVENTOR'S ESTIMATE OF ECONOMY—TRANSMISSION OF FORCE BY MEANS OF AIR HIGHLY COMPRESSED—EXPERIMENTS AT CASCIA ON RESISTANCE OF TUBES TO FLOW OF AIR—LAWS DEDUCED—ABSOLUTE AND RELATIVE RESISTANCES—INCREASE OF POWER WITHOUT INCREASE OF RESISTANCE.

GENERAL OBSERVATIONS.

Next in importance to the creation of a new motive power may be placed any material improvement in the methods of making available the powers which we have. Nature often furnishes us with such powers in abundance in situations where they cannot be conveniently converted to use. The positions of waterfalls are determined by geographical accidents. These do not always conspire with the causes which promote the growth of towns and the development of industries. If it were possible to transfer the immense forces which are thus unprofitably expending themselves to points where there are hands to direct them, and material on which to employ them, they might be made productive of incalculable wealth, which is now lost, and of immeasurable benefit to mankind, which fails at present to be realized.

It is even the case not only with natural but with artificial motors that it is sometimes convenient, and sometimes, indeed, necessary, to apply the power which they furnish at a distance from the source. The excavation of the tunnel under the Alps furnishes just now an example of this description. The drainage of mines and the raising of minerals from their depths furnishes another. In Russia, in the year 1864, the great government manufactory of gunpowder at Okhta was destroyed by a frightful explosion. In the reconstruction of the works it was determined by the minister of war, on the suggestion of General Constantinoff, to erect the several buildings at such a distance from each other that the explosion of one of them should not involve, as happens usually in such cases, the ruin of all the rest. This new manufactory, which has gone into operation during the present year,[1] is composed of thirty-four different workshops or laboratories, to which motive power is transmitted from three turbines, of a total force equal to two hundred and seventy-four

[1] The delay in the publication of this report makes it necessary to remark that the statement in the text relates to the year 1867.

horse-power, along a line nearly a mile in length. Considerations of safety may in like manner often make it desirable to separate by a considerable interval an operation of ordinary industry from the prime mover on which it depends.

Hitherto, in most cases in which such a transmission of power to a distance has been attempted by mechanical means, the losses necessarily incurred have been enormous. Indeed, beyond a certain quite moderate distance, the fraction of the whole force available at the point of application becomes too small to compensate the expense and trouble of the operation, and the undertaking is left unattempted. In the great water-engine at Huelgoat, of which mention has already been made, the transmission of the power is as direct as possible, and is reduced to the last degree of simplicity, and yet so cumbrous are the connections that a force of fifty horse-power is consumed in merely giving motion to the machine without any load. A similar example, but on a comparatively small scale, may be seen at Niagara Falls, near the suspension bridge. In this place there is a gorge through which the waters of the river are forced with an abundance of wasted power sufficient to turn all the machinery in the world. But this power is expending itself between two precipitous cliffs three hundred feet deep. No fraction of it can be turned to use without being first lifted perpendicularly upward through this great interval. For the most part, therefore, it has been allowed to run to waste.

An attempt has been made, nevertheless, to draw from it the insignificant amount of power necessary to drive a saw-mill on the brink of the precipice, and for this purpose a waterwheel has been established at the river's edge, and connected with the saw-mill by means of several long iron rods. These rods are jointed that they may follow the irregularities of the face of the precipice, and receive the support and guidance of stays attached to the rock. The object to be accomplished in this case is small, and the power is abundant, so that a little more or less of waste is a matter of no consequence; but this renders the example more striking, since the power required to move the apparatus of transmission cannot be less than that which is needed to drive the mill.

The great charge upon the prime mover which these cumbrous modes of transmission entail restricts within narrow bounds the extent to which they can be employed. A discovery which shall greatly enlarge these limits cannot but prove to be an inestimable benefit to the world. By bringing into use, and employing to give activity to industry, forces which must otherwise be wholly and permanently unavailable, such an invention is practically a creation of force.

HIRN'S TELODYNAMIC CABLE.

An invention of this kind is presented in the present Exposition, originating with Mr. C. F. Hirn, of Logelbach, on the Rhine. It rests upon a very simple principle, the substitution of velocity of motion for mass of matter moved. No truth is more familiar than that a given

force may be equally represented by a heavy body moving slowly, or a light one moving rapidly. With a smart blow from a light hammer we may easily crush a pebble, while a gentle blow from a very heavy one may produce no effect. In the machine called the wheel and axle a small weight acting on the wheel may raise a large one suspended from the axle through a given space in a given time; but a still smaller one at the wheel will do the same work, provided the size of the wheel be sufficiently enlarged and the velocity of its circumference correspondingly increased.

In the attempts which have hitherto been made to transmit power to distances, it has been the ordinary working velocity of the prime mover which has been transferred from the source to the point of application. In this form we have seen that force is not advantageously transmissible. It was a simple idea, but one truly ingenious, and fertile of admirable results, to transform this power into a shape in which, while it should not be directly applicable to the uses for which it is required, it should, nevertheless, possess the property which it did not possess before, of transportability.

It is this transformation which is the essential part of Mr. Hirn's invention. The motor is made to give a high velocity to a pulley wheel, and this wheel is employed to carry a cable which passes over another pulley at the point where the power is to be applied to use. The cable may be light in proportion as the velocity with which it travels is greater. Theoretically there is no limit to the extent to which this transformation may be carried. A hair or a spider web, if it move fast enough, may convey the force of a thousand horses. Grant that the velocity may be made equal to that of light, and a quantity of matter in the cable wholly inappreciable to the senses will suffice for the same purpose. But there is a practical limit to the velocity with which a pulley can be run, and the cable must have strength to overcome the inertia of the pulleys and the passive resistances of friction on the pivots and of the air. Happily the object in view may be sufficiently attained without transcending the limits here indicated.

The invention thus described, when first presented to the mind, seems easy enough of application. Great difficulties were, nevertheless, encountered by the inventor in reducing it to practice. The cable, though light, requires, when the distance is considerable, to be supported at intermediate points. For this purpose smaller pulleys are introduced at intervals of about one hundred and fifty metres. The cable itself is of wire, about one centimetre in diameter, the extreme pulleys four metres, and the intermediate ones half as large. The great pulleys are driven with a velocity of from one hundred to one hundred and fifty revolutions per minute, or from fifty to seventy-five miles an hour at their circumferences. The smaller must, of course, make twice as many revolutions. In the earlier experiments the wear of the material was found with this rapidity of motion to be enormous. Continual failure was the consequence. One after another different kinds of wood

and different metals were successively tried in the construction of the pulleys. But though their surfaces were made as smooth as possible they rapidly destroyed the cable. They were then covered with leather, with India-rubber, and with other yielding materials, but the cable destroyed these coatings still more rapidly. The substance which was found at last to answer the purpose, and to present a surface, which, without being worn itself, should not wear the cable, was gutta-percha. This is driven compactly into a groove enlarged at the bottom in order to secure it firmly to the wheel, and it has been found so durable that, after a period of seven years use, it still remains sensibly unaltered. The series of experiments which resulted finally in this success extended from 1852 to 1860. In estimating the credit due to the inventor, this perseverance, under discouragements so numerous and protracted, will not be regarded as the least of his merits.

Plate IV will serve to render the general description above given of the telodynamic cable more clear. In Fig. 1 the position of the prime mover is at the extreme left, and that of the receiving station at the right. In this view there are presented two intermediate pairs of pulley supports. Fig. 2 shows the transmission over an eminence intervening between the source of power and the point of application.

The receiving pulley must run, of course, with the same velocity as the transmitting pulley, and as this last has attained its excessive speed of rotation by means of a train of accelerating wheels, connected by bands or gear work, so at the point of application the velocity must be reduced again by a corresponding train retarding.

In Fig. 4 *a*, and Fig. 4 *b*, are shown upon a larger scale the arrangements of the pulleys of the intermediate or supporting stations. The wheels are made as light as is consistent with strength, not only for the sake of reducing the inertia of the moving mass and the friction on the axes to a minimum, but for the more important object of diminishing the resistance of the air. It can hardly be doubted that an abandonment of spokes entirely, and making the pulley a plane disk, would improve essentially the performance, could disks be made at once strong enough to fulfil the required function and light enough not materially to increase the friction. It will be seen further on that the resistance of the air, which Mr. Hirn admits to be equal to the sum of the other resistances, is in fact more than double all the rest put together.

In Fig. 3 is represented the form of the groove into which the armature of gutta-percha is compacted, the figure being a cross-section of the periphery of the wheel. The dovetail enlargement of this groove at the base is necessary, not merely to secure the gutta-percha against dis placement by ordinary causes, but to prevent its being detached by centrifugal force. Mr. Hirn assumes thirty metres per second (98.5 feet) to be the velocity which it is expedient ordinarily to give to the circumference of the wheel; but he has carried this occasionally as high as forty metres, (131.2 feet). At thirty metres the centrifugal force generated at

the circumference of the smaller pulleys, of two metres in diameter, will be between ninety and one hundred times the force of gravity; and at forty it will be nearly one hundred and seventy times gravity. That is to say, as the circumference of such a wheel measures a little over twenty feet round, if each foot of this circumference weighs one pound, the whole will be dragged in all directions with this last velocity by forces which unitedly will amount to nearly a ton and three-quarters. It is on this account that Mr. Hirn suggests that the limit of thirty metres had better not be overpassed, higher velocities endangering the destruction of the wheel.

The invention of Mr. Hirn was first applied in the transmission of moderate powers to moderate distances. Instead of a cable there was used in the beginning a band of steel, having a breadth of about two and one-half inches, and a thickness of one twenty-fifth of an inch. This presented two inconveniences. In the first place, on account of its considerable surface, it was liable to be agitated by the winds; and secondly, it soon became worn and injured at the points where it was riveted. It served, however, very well for eighteen months to transmit a twelve-horse power to a distance of eighty metres (266 feet.) A cable was then substituted, and this, first introduced in 1852, is still in good condition.

It was in the attempt to extend the system to greater distances that the difficulties above spoken of began to be encountered. At the distance of eighty metres no intermediate supports were necessary. At the distance of two hundred and forty to which the system was next extended, such supports were found to be indispensable in order to prevent the cable from dragging on the ground. It was only when, after the many trials and failures above mentioned, a material had at length been discovered which rendered these supports indefinitely durable, that this second experiment could finally be pronounced completely successful. After this success, however, the extension of the system went on rapidly. A single firm, Messrs. Stein & Co., of Mulhouse, have applied it in more than four hundred instances with entire success. These applications have been made for the most part in France, and in the department in which the invention originated, but there are some noticeable exceptions. The government manufactory of powder at Okhta, in Russia, mentioned above, has introduced it for the transmission of the force of its turbines over a distance of one thousand four hundred metres. Several establishments in Germany employ it for distances varying from three hundred and fifty to one thousand two hundred metres. An officer of the Danish navy has made one application of it on a line of one thousand metres; and at the mines of Falun, in Sweden, a more than one hundred horse-power is transmitted by it to a distance of five thousand metres.

The invariable success of all the applications hitherto made, over distances constantly increasing, has satisfied the inventor that power

can be economically carried by this method as far as to ten or fifteen miles. The experience thus far acquired has furnished data by which the loss attendant on transmission can be very closely calculated. This loss, which will of course increase with the distance, may be referred to three sources, viz: the friction on the axles of the pulleys, the rigidity of the cable, and the resistance of the air. Experimentally it is found that, for the two great pulleys at the termini, an allowance must be made of two and one-half per cent., and for the intermediate pulleys and the rigidity of the cable there must be allowed additionally one per cent. for each thousand metres. Thus, for one hundred horse-power carried to a distance of ten kilometres, or six miles, the loss will be $2\frac{1}{2} + 10 = 12\frac{1}{2}$-horse power, or one-eighth of the whole; the resistance of the air being still to be added. Mr. Hirn makes allowance for this by doubling the last sum; so that one hundred horse-power may, in his opinion, with perfect certainty be carried six miles without losing more than twenty-five per cent. It will be shown below that this is an under estimate.

The cost of the machinery and its erection is estimated at 5,000 francs per kilometre, exclusive of the necessary constructions at the termini, which will require an additional expenditure of twenty-five francs per horse-power. In the case of one hundred-horse power carried ten kilometres the total expense will therefore amount to 52,500 francs, or a little over $10,000.

That this mode of transmitting power will soon come into extensive use can hardly be doubted. There are parts of our country in which it cannot fail to be of immense value. The mineral States in the heart of the continent are imperfectly supplied with water-power at the points where it is most to be desired. They are still more imperfectly supplied with fuel. To them it will be an inappreciable benefit to be able to turn to account the force of the mountain-streams which are now running to waste, but which, by means of this invention, may not only be made available, but made repeatedly available, by damming them at different levels. For its practical value, this invention, simple as it appears, is one of the most important that has presented itself in the Exposition; and the jury have shown that they so regard it, by awarding to the inventor the distinction of a grand prize.

Mr. Hirn has presented some calculations designed to illustrate the economical advantages which the telodynamic cable possesses over a rigid shaft or arbor as a means of transmitting force. He proposes, for instance, the problem, what weight of arbor and what power of prime mover would be necessary in order to deliver a force of one hundred horse-power at a distance of twenty kilometres, say two and a half miles. In the solution of this question he has considered the weight of the arbor and the force which would be necessarily consumed in overcoming the friction of its supports; and he concludes at last that the horse-power required in the prime mover would amount to the enormous total of 788,400.

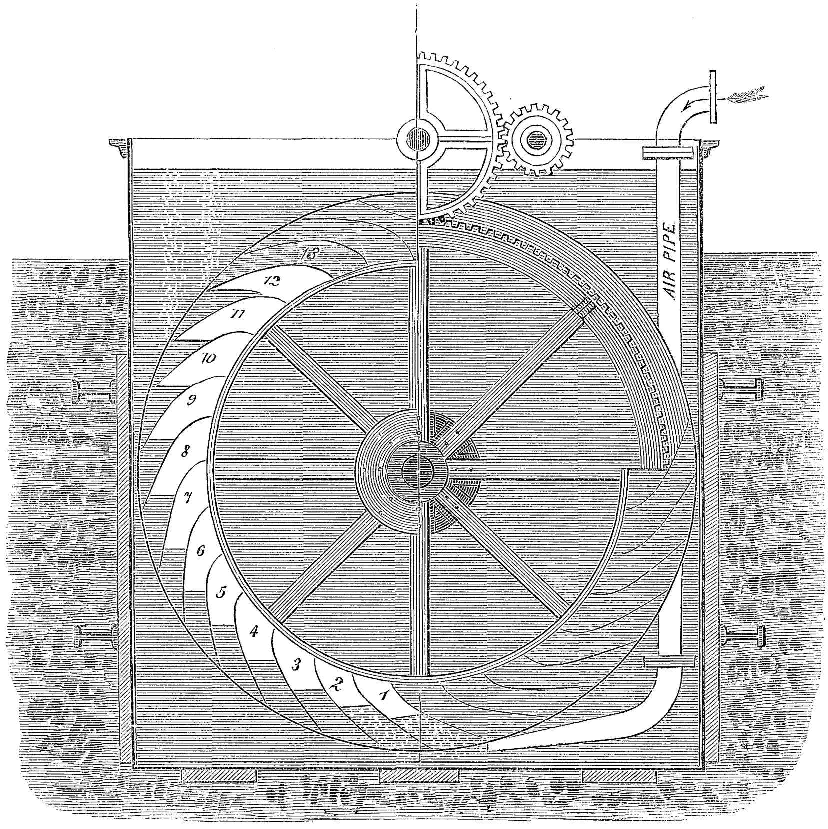
On the other hand, supposing that the prime mover is of the force of two hundred horse-power, and that it is required to know what is the extreme distance at which this motor can deliver a force of one hundred, he finds that this maximum distance would be only 1,545 metres, or less than a mile, (a mile being 1,608 metres.)

The comparison between the two modes of transmission leaves, of course, no place at all to the second. But a comparison so presented is a tacit assumption that in the practical solution of this important mechanical problem there is no other choice but between the two modes of transmission contrasted. Whether or not this assumption is wholly legitimate we shall presently inquire. A different solution of the problem is in fact presented in the Exposition itself, and this will now be considered.

CALLES'S HYDRO-AERO-DYNAMIC WHEEL.

Another mode of transmitting power to great distances, proposed by an exposant from Belgium, Mr. A. Calles, deserves consideration, if not

Fig. 39.



Calles's Hydro-Aero-Dynamic Wheel.

for what it is, at least for what it suggests. The plan of Mr. Calles is to make use of air under a certain degree of compression as the vehicle of the force to be transmitted, not by accumulating the air thus employed in reservoirs, but by driving it, by the operation of the original motor, directly into a tube extending to the point of final application, where it is to be discharged beneath a wheel submerged in water, which it is to turn by its ascensional force. The mode of application is illustrated in Fig. 39.

The idea of employing compressed air as a means of transmitting power is not new; but the mode here suggested of using the power so transmitted is sufficiently original. The exhibitor claims originality in another point of view. His application of the power is not only original in form but in principle also. At Mont Cenis, where air is employed as a vehicle of force, it is the elasticity of the compressed air which furnishes the motive-power. Consequently, it is there important that the compression should be carried very far. It is carried, in fact, up to six atmospheres. The present apparatus proposes to derive its mechanical advantage not from elasticity, but from volume. It is, therefore, here equally important that there should be as little compression as is compatible with the attainment of the object.

The air being employed to turn a submerged wheel, it will be easily understood that the wheel must have the form of an ordinary over-shot water-wheel reversed. In the over-shot wheel, it is the weight of water which is in the buckets of the descending side, while those of the ascending side are empty, which causes the wheel to turn. The motive power is the difference between the counteracting weights of the two sides. In the submerged wheel driven by air, on the contrary, it is the weight of water which is displaced from the buckets of the ascending side, while those of the descending side are full, which is the measure of the driving power. In the present case, as in the former, this driving power is the difference between the weights of the two sides.

It is assumed by the inventor that air immerged in water ascends to the surface with a velocity of one metre per second. In point of fact, the rapidity of ascent of air in water will depend very much upon the volume ascending, and will be, on an average, materially greater than is here stated. But assuming the statement to be correct, it would furnish a limit to the velocity which can be given to the circumference of the wheel; and a given wheel will perform its maximum of work when the supply of air is sufficient to keep its ascending buckets full at half this velocity. Considering, however, that the motive power in the case is gravity, the most advantageous velocity must be necessarily not greatly different from that which experience has shown to be best with the ordinary over-shot wheel working in the air—that is to say, must not exceed one metre per second at the circumference.

The compression of the air must evidently be sufficient to overcome the pressure of the water at the point of efflux beneath the wheel. This

point may be taken at three or four metres of depth, and the corresponding pressure will amount to three or four tenths of an atmosphere. As the air ascends, it resumes by degrees the bulk which belonged to it before compression. In order to take advantage of this circumstance, the velocity of discharge must be so adjusted to that of the wheel that the buckets may not be entirely filled at the bottom. Otherwise there will be an overflow from the rising buckets, and to that extent a loss of motive power.

The inventor takes no account of the resistance of tubes to the flow of air through them. He supposes that at low pressures and low velocities this resistance will be insensible, so that the power received from the source may be almost wholly re-established by the wheel. He has erected a wheel in the park of the Exposition, which is designed to demonstrate the truth of this proposition, and to illustrate his system generally. It is driven by air compressed by an engine in the palace, and transmitted through a tube nine and a half centimetres ($3\frac{3}{4}$ inches) in diameter, and one hundred and fifty-seven metres (more than 500 feet) in length. This tube makes in its course fourteen right angles in order to avoid the constructions which it encounters on its way. It is computed that a force of nine and a half horse-power is expended in compressing the air, and that the velocity of efflux is thirty-two metres (more than 100 feet) per second. On the other hand, the power of the wheel turned by the escaping air is stated at nine horse-power. From these figures it would result that the loss in the present instance is but about five per cent. That there is a fallacy in the calculation is evident from the consideration that the loss of a submerged wheel, driven in this way by air, cannot be less than that of an ordinary over-shot water wheel of the same dimensions; and that this loss is at least one-fifth, and is often more than one-third. And it results from the experiments of the Italian engineers at Coscia, on the resistance of tubes to columns of air driven through them, that to maintain such a velocity as is stated to be given to the air in this experiment, and to the distance named of one hundred and fifty seven metres, there would be required an expenditure of force without return, sufficient to produce a compression of nearly an atmosphere and a half.

TRANSMISSION OF FORCE BY MEANS OF AIR HIGHLY COMPRESSED.

But though the particular mode here proposed of employing compressed air as a means of transmitting force may not seem to recommend itself on the score of economy, it does not follow that the other method, viz., that in which the compressed air is made to act directly by its elasticity, may not be more eligible. This question deserves examination, because if compressed air in tubes will serve economically as a medium of transmitting power, there will be a sensible advantage in employing it instead of the telo-dynamic cables of Mr. Hirn, of which the exposure for great distances above ground, and the many moving parts, constitute so many liabilities to derangement or injury.

The engineers of the Mont Cenis tunnel have expressed themselves strongly in favor of the view that the plan is truly economical, and as their experience in the use of this form of applying power has been larger than any which has been elsewhere enjoyed, their statements deserve consideration. At the date of the report on the progress of the work in the tunnel during the year 1863, they were engaged at a distance of nearly two thousand metres from their reservoirs of condensed air, and were driving nine borers with a force of two and a half horse-power each. The tube conveying he air to the perforators was two decimetres (nearly eight inches) in diameter. The air was under a pressure of six atmosphères, and its velocity in the tube was nine decimetres (three feet) per second. The transmission of the power to this distance, and under these conditions, was attended with no sensible loss. The pressure was not perceptibly less at the working extremity of the tube when all the perforators were in operation, than when the machinery was entirely at rest.

Mention was just made of a series of experiments made at Coscia, in 1837, by order of the Italian government, on the resistance of tubes to the flow of air through them. These experiments were made previously to the commencement of the work upon the tunnel, and while the feasibility of employing compressed air to furnish the motive power of the boring apparatus was considered still questionable. It was the aim of the investigation, not merely to ascertain the absolute loss of force occurring in the transmission of air through tubes of certain particular dimensions, and with certain particular velocities, but to determine, if possible, what are the *laws* which govern the variations of resistance, when the velocities of flow and the diameters of the tubes are varied. From the results of the experiments were deduced the three conclusions following, viz:

1. The resistance is directly as the length of the tube.
2. It is directly as the square of the velocity of flow.
3. It is inversely as the diameter of the tube.

A table was formed exhibiting the numerical values of the resistances which were actually found to exist under the various conditions introduced into the experiments, these values being referred to the common length of one thousand metres. In the actual working of the machines in the tunnel at Bardonneche, where, as just mentioned, no perceptible loss of power was experienced at a distance of two thousand metres from the reservoirs, the tables would indicate that there should be a real loss measured by a diminution of pressure to the extent of six millimetres of the barometric column, one atmosphere of pressure being represented by seven hundred and sixty millimetres. That is, for a tube two decimetres in diameter and a velocity of one metre per second, the tables give a loss of three millimetres of pressure per thousand metres of distance. But six millimetres is but the one hundred and twenty-seventh part of an atmosphere; and as the total pressure amounted to

six atmospheres, the loss, as computed from the tables, would amount to only one one hundred and sixty-fifth part of the total power which the air was capable of exerting. That this loss was not perceptible at Bardonneche was owing to the want of delicacy of the manometer, or pressure gauge, which had only been constructed with a view to show differences of one-tenth of an atmosphere.

A loss, however, which at low velocities and for moderate distances is of insignificant importance, becomes sensible and even serious when the velocity is considerable, and when the distance is greatly increased. Inasmuch as, according to the second of the laws above cited, the resistance varies as the square of the velocity, for a velocity of six metres it will be multiplied by thirty-six while the power will be increased only in the ratio of the volume of air delivered—that is to say, only six times. The *relative resistance*, therefore, or the resistance as represented by a fraction of the power, will be as thirty-six to six—that is to say, will be increased six times. And in general it may be stated that while the length and diameter of a tube remain unaltered, and while the *absolute* resistance which it opposes to the flow of a current of air through it varies as the square of the velocity, the *relative* resistance, or the fraction of the power stored up in the current which the resistance consumes, is only as the simple velocity.

In the case before us, the increase of the velocity to six metres per second, supposing it to take place, would increase the absolute resistance to one hundred and eight millimetres (thirty-six times three) per one thousand metres. Experiment finds the value to be one hundred and seventeen, which, for the distance supposed of two thousand metres, would give a total of two hundred and thirty-four. The absolute resistance would amount then to $\frac{234}{760}=\frac{3}{10}$ nearly of an atmosphere, or $\frac{3}{60}$ of six atmospheres; but the relative resistance would be but the sixth part of this, or $\frac{3}{360}=\frac{1}{120}$ of the total power.

The power of compressed air varies as the product of its pressure and its volume; or when the pressure is constant, as the volume simply. But the volume delivered varies as the velocity multiplied by the square of the diameter of the tube. As the resistance is inversely as the diameter and the volume directly as the square of the diameter when the velocity is given, it follows that under a given pressure and velocity the relative resistance, that is to say the resistance divided by the power, will vary inversely as the cube of the diameter. We may therefore increase the power transmitted, and diminish at the same time the resistances both absolute and relative, by enlarging the diameter of the tube. There is no doubt a practical limit to this expedient, but it would not be to transcend this limit to employ a tube of fifty centimetres, or twenty inches in diameter. The cross-section of such a tube, as compared with the tube of twenty centimetres actually used at Bardonneche, would be $\frac{25}{4}=6\frac{1}{4}$ times larger, and it would discharge, with a velocity of one metre, more than as much air as the latter with a velocity of six. The resist-

ance would also be diminished in proportion to the increase of the diameter—that is, it would be but two-fifths of three millimetres, or a little over one millimetre per thousand metres of distance. This may be considered practically null. It would not amount to a sixth of an atmosphère in one hundred kilometres, or sixty miles of distance.

In the supposition just made we have provided for an increase of power in the ratio of one to six, without any increase of the velocity of the current of air. The same increase might be secured by a smaller enlargement of the tube, accompanied by a moderate acceleration of the movement of the air, and still without a serious increase of resistance. Making the diameter of the tube thirty-five centimetres, a velocity of two metres would suffice to discharge the required volume of air, and the resistance would be eight millimetres per kilometre. With these dimensions and with this velocity the loss of pressure would be about one quarter of an atmosphere, or one twenty-fourth part of the total pressure, in a distance of twenty-five kilometres, or fifteen miles. Or by making the diameter only thirty centimetres, the velocity required would be 2.7 metres, with a resistance of seventeen millimetres per kilometre, which would amount to a quarter of an atmosphere in eleven kilometres, or six and a half miles.

In the comparisons made above between the loss of pressure in the several cases supposed and the total pressure, account is not taken of the fact that the total pressure cannot be effectively employed in work. It is only the excess of the pressure of the compressed air over that of the atmosphere which can be turned to account. The effective pressure, in the present instance, is therefore but five atmospheres. Comparing with this the losses as computed above, we shall have:

For a power transmitted one hundred kilometres by means of compressed air of six atmospheres moving in a tube of fifty centimetres in diameter, with a velocity of one metre per second, a loss of one-thirtieth, or three per cent. of the whole.

For a power transmitted twenty-five kilometres, with air of similar pressure, in a tube of thirty-five centimetres in diameter, and having a velocity of two metres, a loss of one-twentieth, or five per cent. of the whole.

For a power transmitted eleven kilometres, with air of similar pressure, in a tube of thirty centimetres in diameter, and having a velocity of two and seven-tenths metres, a loss of one-twentieth also, or five per cent. In this case, if the distance be made twenty-five kilometres, the loss will be increased to one-ninth, or eleven per cent. of the whole.

These results are favorable; and if all the loss of power attendant on the use of compressed air as a means of transmitting force to points distant from the source were embraced in those arising from the resistance of tubes, they might be said to be conclusive. How far this is true will presently be examined.

Previously to the commencement of operations at Bardonneche, it

was confidently predicted by many who doubted the feasibility of the plan adopted, that the leakage would be enormous. This cause alone, it was affirmed, would render the system abortive. It was maintained that the air could not fail to escape through joints the most accurately fitted, and possibly even through the pores of the metal. It is a little surprising that an apprehension like this last should ever have been expressed, in view of the fact that steam, which is considerably more subtile than air, is habitually confined under greater pressures than that of six atmospheres, without oozing through the walls of the vessels containing it. In regard to the possibilities of leakage at joints, the objection was more plausible, but experience has fully demonstrated its fallacy. No leak has ever been detected, though the tube has been often tested with candle flames throughout its whole length. Nor have the expansions and contractions attendant on changes of temperature due to the successive seasons, affected sensibly the firmness of the junctions. On one occasion it became necessary to leave the receivers full of compressed air for twenty-four successive days. The loss in all that time did not exceed the five-thousandth part of the daily supply.

The engineers of the tunnel are therefore convinced not only that the transportation of motive power to great distances by means of compressed air is practicable, but that under certain circumstances it may be largely economical. They give the following hypothetical example in illustration. With a view to avoid introducing into their calculation any element in regard to which experiment and practice have not furnished positive data, they assume for the diameter of the tube thirty centimetres; and for the velocity of the air in it, six metres per second. They suppose then that a water-power is found of sufficient force to maintain in this tube a flow of air at this assumed velocity, under a compression of from six to twelve atmospheres, as may be desired. And they further suppose that this power is to be transported to a distance of twenty kilometres, or twelve miles.

A tube of thirty centimetres in diameter will discharge four hundred and twenty-four cubic decimetres of air in one second at the velocity of six metres. Each cubic decimetre of air under the pressure of six atmospheres is assumed by the authors of the report to represent a power of work measured by one hundred and ten kilograms raised one metre, or, in technical language, one hundred and ten kilogram-metres. Hence, the total volume discharged per second will have a force of 46,640 kilogram-metres; which, being converted into horse-power, by estimating, as is usual, the horsepower at seventy-five kilogram-metres per second, will amount to six hundred and twenty-two horse-power. From this must be deducted the resistance of the tube.

According to the tables deduced from the experiments at Coscia, the resistance of a tube of thirty centimetres diameter to air moving six metres per second, is equivalent to an opposing pressure of seventy-

eight barometric millimetres per kilometre of distance. Hence, for twenty kilometres, it will be $1^{m}.56$. And $1.56 \div 0.76 = 2.05$ atmospheres. The air must, therefore, be compressed to eight atmospheres, in order to secure its discharge at twenty kilometres of distance with a pressure of six atmospheres and a velocity of six metres. In other words, there must be a loss of twenty-five per cent. of the original force, and seventy-five per cent. will remain available. But suppose that, instead of seventy-five, there be but sixty per cent. of the theoretic horse-power realized, there will still remain 373 horse-power disposable for use.

The cost of the tube laid down and ready for work is estimated at fr. 800,000=$160,000; being $8,000 per kilometre or $13,000 per mile. This estimate is probably abundantly large, as the tube would weigh only about one hundred tons to the kilometre, or 2,000 tons for the entire distance. Two thousand tons, at $50 per ton, would amount to one hundred thousand dollars; leaving $60,000, or nearly $5,000 per mile, for transportation and laying.

The interest on the investment would, at six per cent. amount to $9,600 per annum, which would be equivalent to $25 75 per horse-power per annum; and this for a power working night and day. A steam-engine working in like manner constantly, would consume about twenty-one tons of coal per horse-power per annum, allowing five pounds per horse-power per hour. This is a large allowance, but reducing it to three pounds per hour or twelve tons per annum, there would still, with coal at $5 per ton, be a large balance in favor of the economy of the power derived from the compressed air.

The authors of the report further estimate that a larger power, say one of eight or ten thousand horse-power, carried to a greater distance, say fifty kilometres, or thirty miles, would cost pro rata much less; not more perhaps than one-half or one-third the amount above computed. Thus it is observed that the cascade of Marmora, on the Avellino, offers a minimum theoretic horse-power of 160,000, of which 20,000 at least might be conveyed fifty kilometres or more from the source, through the medium of compressed air, and a great deal more cheaply than an equivalent amount of power could be created by steam at the place where it is applied.

These calculations seem conclusive; and if it is true that they are in all respects correct, and that they embrace all the sources of loss attendant on this mode of transmitting power, they must be regarded as being conclusive in fact. It is to be borne in mind, however, that whenever air, or any other elastic fluid, is compressed by force, there is generated an amount of heat which is the exact equivalent of the force employed in the compression, and which elevates the temperature of the air compressed. Were this elevated temperature to remain permanent, it would be reconverted into force on the subsequent expansion of the air in working, and no loss would result. But as the original temperature is that of the weather and of all surrounding things, the temperature of

compression is above the general level, and in the natural tendency of heat to equilibrium, it must soon disappear. If the air, after compression, were to be imprisoned in a receiver of invariable capacity, the fall of temperature would be attended with a corresponding fall of pressure; and as the work which by re-expansion, after compression, air is capable of performing, is dependent upon pressure and volume conjointly, there cannot but occur here a serious loss. There is actually a loss, by cooling, of exactly as much power as was employed in the compression; but as the air, in consequence of its change of density, remains still under a pressure much superior to that of the atmosphere, it is capable of still doing work, and if allowed to expand will do it at the expense of the heat which it contains at the natural temperature. In its expansion, its own temperature will accordingly be depressed, but not by any means so much as it was raised during compression.

The amount of the loss resulting from this circumstance admits of being exactly computed. It will vary with the absolute pressure to which the air is subjected. To take the case at Bardonneche where a pressure of six atmospheres is aimed at and secured, for every hundred horse-power employed in compression, sixty horse-power only remain available after the heat produced by compression has passed away. In this case, the air, instead of being reduced to one-sixth of its volume by the force which raises its pressure to six atmospheres, as it would be if there were no heat generated, actually begins to enter the reservoir when its volume is reduced only in the proportion of 3.6 to one. Its density is therefore 3.6 times that of the common air. As the reservoir into which it is driven at Bardonneche is not one of invariable capacity, but is maintained by a hydraulic head under the constant pressure of six atmospheres, its density increases as it cools, and becomes equal to 6, when at length it has attained the original or normal temperature of the weather. But this increase of density is attendant with a correspondent diminution of volume, while the pressure remains unaltered, so that the amount of work it is capable of doing is reduced just in proportion to the contraction, that is, in the proportion of 6 to 3.6, or one to six-tenths.

If it were designed to employ higher pressures, the loss would be in still greater ratio. Thus, should air be forced into a reservoir under a hydraulic head equal to eight atmospheres, it would happen that for every one hundred horse-power of compressing force expended, there would ultimately remain only fifty-five horse-power available for subsequent use. At a compression of eleven atmospheres, (more exactly 10.845,) the loss would amount to precisely one-half. On the other hand, at a compression of only four atmospheres there would be secured sixty-seven per cent. of the compressing power; at a compression of three atmospheres, seventy-three per cent; and at a compression of two, eighty-five per cent.

The engineers of Mont Cenis have taken no account of this very seri-

ous source of loss. They do not fail to recognize the fact that a loss occurs, but they treat it as unimportant. Their only notice of it is in the following paragraph:

"There is a final consideration to be mentioned in regard to the compression of air, which, to say the truth, interests rather physical science than the practical application of the system of compression. Air, when compressed, abandons a part of its latent heat, which becomes sensible and diffuses itself among surrounding media. We fail of data to enable us to judge of the degree of influence which this fact infallibly exercises upon the motive power which operates the compression; we can say, however, on the other hand, that, industrially speaking, it is of an importance so small that it may be entirely neglected. At any rate, our previsions for estimating the disposable force necessary to produce a certain quantity of compressed air having been founded always upon experimental data derived from the effects of compression actually performed, we have thus made allowance for the resistances proceeding from this phenomenon, and we can accordingly defer its more accurate study, which we reserve for future attention.

"Meanwhile we cannot but suggest that the fact of the production of heat in the compression of air giving place to the inverse phenomenon when the air resumes its original volume—this second fact is for us in the highest degree advantageous. The air flowing into the extremity of the gallery at the tension of six atmospheres, in resuming by dilatation the tension of the common air, absorbs from surrounding media the same quantity of heat which it had emitted in the act of compression; and this absorption of heat tends to depress the temperature of the gallery, which is naturally elevated, and is made more so by the presence of the workmen and by the combustion of the lamps and the gas beaks."

The authors of the report, by deferring to the future the more particular study of the influence which the compression of air must have upon the economical value of this mode of transmitting force to distances, have permitted themselves to fall into a serious error. They have failed to detect the fact that the loss is not unimportant; and they have assumed too hastily that the heat taken up by the air in expanding is equal in amount to that which it had emitted while undergoing compression. The difference is very large. To them, and for the purposes which they had in view, it was indeed a matter of no practical importance whether, abstractly considered, the mode was economical or not. The force was needed in the tunnel; compressed air offered the most advantageous expedient for introducing it there, and the water power required to compress it was withdrawn from no useful purpose, but was running to waste. The question whether or not the fraction of this wasted power which was turned to account was or was not the largest possible, was a question of secondary importance so long as this fraction was adequate to the work to which it was to be applied. It is sufficiently evident, nevertheless, that the compressing engines established

at Bardonneche have never produced in practice the quantity of compressed air which was expected from them.

The construction of these compressors is very simple. They operate by applying the living force of a large column of water descending in an inclined tube, to drive a body of confined air into a receiver within which there is maintained a constant pressure of six atmospheres by means of a hydraulic head. Each compressing engine resembles therefore, substantially, a huge inverted siphon, having the long arm inclined and the short arm vertical. The cross-section of this siphon is uniform throughout, except at a point in the long arm near the bend, where there is introduced a valve for the purpose of regulating the periods of motion and rest of the contained water column. At this point the tube is enlarged so as to make the valve opening equal to the full cross-section of the tube, and the valve itself, which is a spindle or puppet valve of peculiar form, somewhat ovoid in shape, or resembling rather a boy's peg top, drops in opening into a chamber, formed by the enlargement of the tube, of such dimensions that the annular space allowed for the flow of the water around it is still equal to the same cross-section. These precautions are taken to prevent the loss of living force by any change in the velocity of the moving mass.

The short arm of the siphon is the chamber into which is introduced the air to be compressed. At its upper extremity it communicates by a valve with the receiver of compressed air. This valve is kept closed by the pressure of the air in the receiver, so long as the pressure beneath it is less, but when the air beneath attains by compression the same tension as that already in the receiver, the valve opens and the new charge enters.

The compression chamber, or short arm of the siphon, receives its successive charges of air from the atmosphere by valves opening inwards. It is freed from water after each pulsation or act of compression, by means of other valves, which open at a level somewhat above the bend of the siphon, so that the bend itself and the long arm remain always full of water.

The action of the machine will now be easily comprehended. The air chamber being full of air at the ordinary density of the atmosphere, the great valve in the long arm of the siphon is opened, and the water rushes through the bend into the short arm, compressing the air before it, and finally driving it into the receiver. The water then comes to rest, the large valve of the long arm closes, the discharge valve of the short arm opens, the water escapes and a new charge of air enters.

The difference of level between the head of the driving column of water and the point of discharge is twenty-six metres. The diameter of the tube is sixty centimetres, and the height of the air chamber, measured from the level of discharge at bottom to the valve opening into the recipient at top, is four metres. These measurements would give for the total capacity of the air chamber 1.13 cubic metres; and this is the maximum charge

which the machine is capable of compressing at a single impulse. The charge actually compressed, however, is less than this, and is determined by the condition that the resistance which it opposes to the driving force, during its compression and subsequent passage into the recipient, shall exhaust this force exactly, without excess or deficiency. In case the resistance is in excess, a portion of the air will fail to pass into the receiver and so be lost. In case it is in deficiency a portion of the motive power will be uselessly expended, and, moreover, the column of water will strike the top of the air chamber with violence, and may damage the machine. The practical adjustment of the bulk of the charge to the power of the engine is attained by a tentative process, a series of small valves being adapted to the side of the air chamber in a vertical row, through which the air can escape, but which the water by its inertia closes successively as it rises. If, in a series of experiments, these valves be secured one after another, beginning at the top, the charge of air will be gradually increased, until at length it is found to have the volume required.

There are at Bardonneche ten of these compressors constantly at work, each one making three impulses per minute, or 4,320 per day. If the charge at each impulse were equal to the capacity of the air chamber, the total volume of air compressed daily would be 48,816 cubic metres, which, reduced to one-sixth its bulk, would occupy in the receiver a space of 8,136 cubic metres. It appears that the volume actually compressed amounts to only 23,400 cubic metres, so that the charge in the compressor is but fifty-four hundredths of one cubic metre at each impulse.

If we make a comparison now between the results actually reached and the compressing force employed, we shall see that the loss in practice has proved considerably larger than that which, according to the foregoing statements, theory would indicate. The power of each compression machine is equivalent to that which would be generated by the descent of a vertical column of water twenty-four metres in length and sixty centimetres in diameter through a space of four meters, three times per minute through the day.[1] The calculation shows that this

[1] The column is not vertical but inclined. The mechanical effect, however, (friction being disregarded,) is the same as if it were vertical. The length of the inclined column is greater than the vertical difference of level, in the ratio of radius to the cosine of the deviation from the vertical. But as the movement of the water in the tube at each impulse is constantly four metres in the direction of the axis, the descent in the direction of gravity is diminished by the inclination in the same proportion as the length of the column is increased.

The vertical distance between the levels is twenty-six metres. The rising of the water four metres in the short arm of the siphon neutralizes the effect of the four metres at the foot of the descending column. But for the influx of water from the reservoir at the top, the driving column would be effectively reduced to twenty-two metres. But this inflowing water, filling the four metres at the upper extremity of the tube, has a mean descent of two metres, and renders the total mechanical effect of the entire descending column equal to that of a vertical volume of twenty-four metres, as stated above.

Then, as there are three impulses per minute; and, as each cubic metre of water weighs one thousand kilograms; and, moreover, as the value of one horse-power is ordinarily taken at

would a little exceed an eighteen horse-power. The whole ten of the compressors furnish, accordingly, a horse-power of one hundred and eighty.

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seventy-five kilogrammetres per second, or 4,500 per minute, the power of one machine will be expressed by

$$24 \times \overline{0.60}^2 \times \tfrac{1}{4}\pi \times 4 \times 1000 = 18.096 \text{ horse-power.}$$

And as there are ten machines, the total horse power will be 180 96, or 181, nearly.

The calculations which follow, on the effects of the heat developed in the compression of air, or absorbed in its expansion, rest upon established principles of thermotics, which are concisely expressed in the following formulæ:

Let v and p be taken to denote, generally, the volume and pressure of any body of air or other perfectly elastic fluid, and t the temperature of the same body, as reckoned in degrees from the absolute zero—that is, from a point 273° C. below the zero of the centigrade thermometer.

Let v_0, p_0, and t_0 represent the volume, pressure, and temperature of a particular mass of air in its initial condition, and v_1, p_1, and t_1 the corresponding properties of the same mass, after its condition in some or all of these particulars has been changed.

Let the ratio of the specific heat of air at constant pressure and at constant volume be represented by the letter γ.

Then if the volume of the air changes by expanding against pressure, or by contraction under superior pressure, the temperature will also change, unless a certain amount of heat be supplied in the first instance or withdrawn in the second. But if, by such means, the temperature be maintained constant—that is, if, after the change, $t_1 = t_0$, then the following equal tions will be true:

$$p_0 v_0 = p_1 v_1, \text{ and } \frac{p_0}{p_1} = \frac{v_1}{v_0}.$$

That is to say, when temperature is constant, pressure is inversely as volume. This proposition is commonly known by the name of the LAW OF MARIOTTE.

If the volume remain constant while the other conditions vary, then

$$p_0 t_1 = p_1 t_0, \text{ and } \frac{p_0}{p_1} = \frac{t_0}{t_1}.$$

That is, when the volume is constant, the pressure is directly as the temperature

If the pressure remain constant, while the volume and temperature vary, then

$$v_0 t_1 = v_1 t_0, \text{ and } \frac{v_0}{v_1} = \frac{t_0}{t_1}.$$

That is, when the pressure is constant, the volume is directly as the temperature. This is called the LAW OF GAY-LUSSAC.

Finally, if all three of the conditions vary, while the air neither receives any heat from surrounding media nor imparts any to such media, we have

$$\frac{p_1}{p_0} = \left(\frac{v_0}{v_1}\right)^{\gamma}, \text{ and } \frac{t_1}{t_0} = \left(\frac{v_1}{v_0}\right)^{\gamma - 1}$$

From whence are deduced the several values of p_1, v_1, and t_1 which follow, viz:

$$p_1 = p_0 \left(\frac{v_0}{v_1}\right)^{\gamma}. \qquad p_1 = p_0 \left(\frac{t_1}{t_0}\right)^{\frac{\gamma}{\gamma-1}}.$$

$$v_1 = v_0 \left(\frac{p_0}{p_1}\right)^{\frac{1}{\gamma}}. \qquad v_1 = v_0 \left(\frac{t_1}{t_0}\right)^{\frac{1}{\gamma-1}}.$$

$$t_1 = t_0 \left(\frac{v_1}{v_0}\right)^{\gamma-1}. \qquad t_1 = t_0 \left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}}.$$

These are known as the EQUATIONS OF POISSON.

The amount of work required to reduce a given volume of air to a smaller volume, answering to a given superior pressure, and to force it into a reservoir at that pressure; or, what is the same thing, the amount of work which the same mass of air, taken at the superior pres-

On supposition that the compression-chambers are entirely filled with air at each impulse, this power will not be equal to the work imposed upon it. But if, instead of 1.13 cubic metres, there be admitted only 0.78 cubic metres at each charge, the total resistance will be exactly equal to the power. Were not heat developed by the compression, the charge might be made as large as 0.94 cubic metres and the total amount of daily compression would be 40,608 cubic metres. It would seem, from the dimensions adopted, as if the original expectation had been to compress one cubic metre at each pulsation of each machine. Had that expectation been realized the compression would have reached to 43,200 cubic metres daily, reduced to 7,200 cubic metres in volume.

The power employed is actually capable of compressing 33,860 cubic metres daily, to a bulk under the pressure of six atmospheres of 9,500 cubic metres, becoming by subsequent contraction 5,700 cubic metres. But the amount actually compressed is only 23,400 cubic metres daily, giving ultimately 3,900 cubic metres of compressed air at the normal temperature. This represents a compressing force of only one hundred and twenty-five horse-power, being less by fifty-five than the theoretic force of the compressors.

The 3,900 cubic metres at the pressure of six atmospheres are capable of producing an amount of work hardly equivalent to seventy-five horse-power. There is therefore a loss at Bardonneche, from causes known and unknown, equal to seven-twelfths of the hydraulic force employed.

It is probable that a part of the loss unaccounted for as above may be a necessary consequence of this mode of applying the *vis viva* of an inert mass in overcoming elasticity. In order to avoid injury to the machine, and also to prevent water from passing along with the air into the recipient, the charge must be large enough. The danger is that it will be made too large, and that a part of the compressed air will fail to enter the recipient. All the force expended upon this portion is thrown away. Another part of the loss may be due to the inertia of a body of water occupying the bend of the siphon, about two cubic metres in bulk, which comes to rest after every pulsation, and opposes the movement of the driving column. The same hydraulic power, or an equivalent steam

sure, is capable of furnishing, in being first introduced into the cylinder of an engine, and afterwards expanding to the inferior, may be found by the following formula, in which w represents this work:

$$w = p_1 v_1 \left(1 + \frac{v_0^{\gamma-1} - v_1^{\gamma-1}}{(\gamma-1) v_0^{\gamma-1}} \right) = p_1 v_1 \frac{\gamma v_0^{\gamma-1} - v_1^{\gamma-1}}{(\gamma-1) v_0^{\gamma-1}}.$$

A formula founded on the law of Mariotte, and which assumes that the temperature of the air remains constant during its expansion or compression, has been much used in calculations of this nature, but with results necessarily erroneous in proportion as the change of volume is greater. It is the following:

$$w = p_1 v_1 \left(1 + \text{h. l.} \frac{v_0}{v_1} \right)$$

in which v_0 is supposed to be the larger volume, and the abreviation h. l. stands for hyperbolic logarithm.

power, would probably be applied more effectually in compressing air by means of pumps, than in the method above described. This the engineers themselves appear to have tacitly admitted, by introducing pumps at the northern entrance of the tunnel.

It must be finally observed, as having an important bearing upon the question of economy in regard to this mode of transmitting power, that the work which remains stored up in compressed air, after the important deductions we have found it necessary to make, cannot be fully recovered without working the air expansively down to the pressure of the atmosphere. If it has been compressed to six atmospheres, it must be expanded more than three and a half times; if to eight, nearly four and a half; if only to three, to two and a quarter times. At Bardonneche, where the perforators work without expansion altogether, half the power is thrown away.

If we apply the results which we have thus reached to the example above quoted from the report of the engineers of Mont Cenis, we have to make some important modifications of the results there presented. The proposition is to carry to a distance of twenty kilometres, by means of a tube thirty centimetres in diameter, a force represented by an efflux of four hundred and twenty-four cubic decimetres of air per second under a pressure of six atmospheres. It is first necessary to recompute the value of the power which this discharge is capable of affording. The engineers have assumed, what would be true according to the law of Mariotte, viz: that the pressure of an elastic fluid is inversely as its density, that each litre of the air delivered, as above supposed, would represent a power of work equal to one hundred and ten kilogrammetres. Taking into account, however, the depression of temperature attendant on expansion, this power must be reduced to 61.41 kilogrammetres only. But we must increase this again by the amount of force which the air exerts in being introduced into the working cylinder of the machine which it operates, that is, by the amount of sixty-two kilogrammetres per litre, so that the actual force which each litre represents will be carried up to 123.41 kilogram-metres. A supply of four hundred and twenty-four litres per second, with this value, will then furnish a horse-power of six hundred and ninety-eight, say seven hundred, but in order to produce it there will be required an original expenditure of eleven hundred and seventy-five horse-power.

Since, moreover, it appears that the resistances of the tube will call for an increase of the pressure at the source to eight atmospheres, a corresponding addition must be made to this original expenditure. Supposing the volume of air condensed to remain the same, but to be compressed as above required to eight atmospheres, the force necessary for this compression will be no less than one thousand three hundred and fifty horse-power, and the force which the air so compressed would be capable of exerting, if used on the spot, would be only seven hundred and forty horse-power. At the distance of twenty kilometres, it would

fall, as above, to seven hundred; so that the loss from all causes would amount to nearly fifty per cent.

It is therefore evident that, under the conditions which we have been considering, that is to say, in the use of great pressures and tubes of moderate dimensions, compressed air does not furnish an economical mode of transmitting power. At lower pressures, the original loss is less; and in tubes of larger diameter the resistance in the movement of transmission is less. A tube of fifty centimetres in diameter will deliver the same volume of air at a velocity but little more than two metres per second, and with a resistance of only seven and a half millimetres of barometric pressure per kilometre of distance; which, for twenty kilometres, amounts to one-fifth of an atmosphere. Supposing this air to be originally compressed to three atmospheres, it will deliver a power of two hundred and sixty horse at a distance of twenty kilometres with an expenditure at the source of four hundred horse-power. This will be sixty-five per cent. of the whole. Of the loss, thirty-five per cent. in all, twenty-seven per cent. will be incurred at the point of compression, and eight per cent. in consequence of the resistance of the tube. At the distance of fifty kilometres, or thirty miles, the power delivered will still amount to two hundred and twenty, or fifty-five per cent. of the original expenditure.

It may be interesting to compare this result with that which would be obtained in the application of Mr. Hirn's telodynamic cables to the transmission of a similar power to an equal distance. His allowances for losses are two and a half per cent. of the whole power for the resistances of the two great pulleys at the termini, and eighty-four kilogrammetres per kilometre of distance for the friction of the pulley supports. To these must be added the effect of the resistance of the air and of the rigidity of the cable. On four hundred horse-power the first deduction would be ten. The friction on the pulley supports in fifty kilometres would consume thirty-six horse-power more. For the determination of the resistance of the air to the pulleys the data are imperfect, but an approximate estimate may be formed by considering that the velocity at the circumference of the pulleys is thirty metres per second, and has been carried to forty metres. At thirty metres of velocity the resisting pressure of the air upon a moving body is more than one hundred and twenty kilograms per square metre of surface directly exposed to it. Each pulley has eight spokes, exposing each a surface of three or four one-hundredth parts of a square metre—say one-fourth of a square metre in all. If we take the atmospheric resistance due only to two-thirds of the circumferential velocity, which resistance is fifty-four kilograms per square metre, the force required to overcome it will amount to 13.5 kilogrammetres for each pulley, or to twenty-seven for the pair of pulleys, and to one hundred and eighty-nine, equal to two and a half horse-power, for the seven pairs in a kilometre. Fifty kilometres will, therefore, consume one hundred and twenty-five horse-power, which added to the consumption above computed for friction, will give a total

of one hundred and ninety-one. This being deducted from the entire original force will leave two hundred and nine horse-power; the resistance due to the lateral friction of the air and to the rigidity of the cable being still to be allowed for. It follows that, for great distances, the transmission of power by compressed air may compete favorably with the only other mode of transmission which could be substituted for it; while, for moderate distances, it is economically inferior. For great distances, whatever mode of transmission be employed, there must always be a very considerable loss. This will be true even with water, whether conveyed in canals or in tubes; while water power can only be so conveyed to points at levels lower than the source.

There are parts of our country in which the means of transmitting power to distances are of high importance. In certain portions of our mineral regions the possession of a few hundred horse-power may make to a whole community all the difference between poverty and wealth. If this power can be obtained from the distant mountain torrents by either of the methods which we have been considering, it is certainly better to submit to the loss which they entail than not to obtain it at all. There is an incalculable amount of force constantly wasting itself in the natural world, which never will or can be applied to any useful purpose at the points where it is developed. If the half or the third or the tenth part of such a force can be transported into the heart of an industrial community, the abstract economy of the means of transportation is a matter of secondary importance, provided there are no better means. It may, therefore, be justly concluded that the use of compressed air as a medium for transmitting power, if not theoretically as advantageous as at first thought it might seem, may, under circumstances of not very unfrequent occurrence, be an invaluable expedient for turning to useful account powers which would otherwise be wholly unavailable.

CHAPTER IV.

ACCUMULATION OF FORCE.

ACCUMULATION OF FORCE BY COMPRESSION OF WATER—SIR WILLIAM ARMSTRONG'S METHOD—ACCUMULATOR OF GOUIN & CO.—ACCUMULATION IN FLY-WHEELS—THE MAHOVOS; A CONTRIVANCE FOR THE PROMOTION OF ECONOMY IN RAILWAY TRANSPORTATION—ITS CONSTRUCTION—ILLUSTRATION OF THE ADVANTAGES TO BE DERIVED FROM ITS USE—APPLICATION OF THE MAHOVOS AS A BRAKE.

ACCUMULATION BY COMPRESSION OF WATER.

Messrs. Gouin & Co., of Paris, have employed, in certain operations of tunnelling, a mode of transmitting power, in which the medium used is water under heavy compression. This method has, also, for some years been employed in foundries, factories, and other industrial establishments in England, for the purpose of storing up the power of a prime mover during the intervals in which its work is not required in driving the machinery of the establishment for the use of which it was erected. For this purpose it was originally introduced by Sir William Armstrong, and it was exhibited by him at the London Exposition of 1862. The method consists in accumulating a large quantity of water in a strong cylinder, placed vertically, and closed by a piston which is heavily weighted. The water may be pumped in by the ordinary motor of an industrial establishment when it is not otherwise employed, and may be subsequently used to drive one or more hydraulic engines. This mode of accumulation is especially useful in cases in which a large power may be needed for some particular operations which only occur at intervals, and for the sake of which only it would not be consistent with economy to provide a motor of adequate power, which could only be made serviceable at such intervals, and would be required to lie a great part of the time idle. A feeble motor may, in an extended time, accumulate a hydraulic force of great energy; and this can afterwards be expended as it was accumulated, by degrees; or, if necessary, all at once.

This contrivance is evidently not adapted to the general purposes of the transmission of power to distances; for, in the first place, the loss of force by friction in the tubes which must be employed to convey the water would be very serious; and in the second, since water is practically unchangeable in volume by compression, and since the accumulation in the reservoir cannot be greater than is consistent with the security of the reservoir itself there is a natural limitation to the quantity that can be accumulated. But for working machines at short dis-

tances from the original prime mover, and especially for the working of several small machines at different but not very distant points by the instrumentality of a single larger one, this expedient may become both convenient and economical. Such is the application which has been made of it by Messrs. Gouin & Co. in the perforation of tunnels in the Apennines. In the construction of these tunnels several shafts were sunk at different points along the line. For the purpose of raising the earth excavated it was necessary to establish elevators of some description at each shaft. The constructors resolved to employ cranes, actuated by hydraulic engines; and, in furtherance of this plan, they established an accumulator into which water was driven by a single steam-engine, where it was compressed to the enormous extent of forty atmospheres.[1]

When the force of compressed water is to be employed in the constant repetition of a certain effort through a limited space, the simplest and most economical mode of application is by direct action. It is in this mode that it is employed in such cases by Sir William Armstrong, the cylinder of the hydraulic machine being made of a length equal to the space through which the effort is required. For larger movements the oscillating hydraulic engines of Ramsbottom, already described, are used; two cylinders with their pistons acting alternately upon the same shaft.

In the construction of accumulators a loaded piston, which in its movement generates a volume equal to that of the water introduced, is, of course, necessary. Were the pressure applied in any other manner than by weight, as, for instance, by the elastic reaction of confined air, it could not continue to be sensibly constant while the head is drawn down. For this reason it will be obvious that, if by the continuance of the action of the supply pumps, while no demand is made upon the reservoir, the accumulation becomes excessive, the piston may become unstable and so topple over; an accident which, considering the enormous weight which it carries, would be very serious were it permitted to occur. Two safeguards have been adopted by Sir William Armstrong to prevent such a catastrophe. The limiting altitude of safety having been ascertained, a connection is established between the piston and a valve placed on the induction pipe of the steam-engine working the pumps; and this provision begins to take effect as the limit of safety is approached, and closes the valve entirely the moment it is reached. The pumps accordingly cease to act, and no more water can be introduced into the reservoir until after the supply already accumulated has been to some extent reduced. To provide against the possibility of the failure of this contrivance there is added a second one, by means of which, whenever the piston rises higher than it ought, a stop-cock is opened, and water from the accumulator itself is allowed to escape until the proper level is restored. In the accumulator of Messrs. Gouin & Co. the provision to meet this case of inse-

[1] In some of the British foundries the pressure in these accumulators is carried up to fifty, sixty, and even one hundred atmospheres.

curity is particularly deserving of attention. It having been found that when water was permitted to escape by a cock there was danger of too sudden an arrest of the efflux, in consequence of which the whole machine acted like an enormous hydraulic ram, with danger of bursting the cylinder, or other injury, these constructors gave to their safety-valve the form of a piston plunger, which is gradually raised as the level of security is passed. This plunger is made hollow, and in one of its sides is a longitudinal groove, which gives an increased water-way the higher the valve is raised, but which shuts off the water so gradually in the descent as to prevent all liability to concussion.

ACCUMULATION IN FLY-WHEELS.

THE MAHOVOS.

Among accumulators of power must be classed the Mahovos, a contrivance invented by Captain Carl Von Schuberszky, a staff officer of the Russian corps of engineers, to promote economy in railway transportation and in railway engineering. Captain Schuberszky justly remarks that though the railroad system of the present day has attained to such a degree of development as to be adequate to provide for the largest traffic with pecuniary profit, still it does not yet adapt itself to routes of smaller traffic, which, though separately of minor importance, yet, in consequence of their greater number, are in the point of view of statesmanship most worthy to be fostered. The disadvantage under which the minor routes lie is, that the capital invested in them brings no adequate return; so that the possibility of their maintenance, or even of their original construction, must depend, in many cases, on the possibility of reducing within a moderate limit both the cost of laying the way and that of operating it after it is laid. The main cause of the expensiveness of railways is the irregularity of the earth's surface. In a country, if such an one could be found, over which there should prevail from one end to the other a uniform dead level, railroads would be cheap enough to pay for construction upon almost any route. But wherever inequalities exist, and that is almost everywhere, these must be overcome by expedients which are all costly, and between which it is sometimes difficult to choose. These expedients reduce themselves to three, viz:

1. To reduce the inequalities, by cutting through hills and filling up hollows, at whatever cost.
2. To evade the inequalities, by giving to the road a serpentine track.
3. To permit the inequalities to remain, reducing them only within a certain determinate limit of inclination.

Of these three possible modes of proceeding the first is the most costly per linear mile of way constructed; and when the inequalities are heavy, and especially when the cutting is in rock, it is usually too costly to be adopted except where there exists a certainty of a very remunerative traffic. Nevertheless, in general, as a road constructed on this plan will be

the shortest possible, and most nearly level, (quite level, indeed, if the termini are at the same elevation as referred to a horizontal plane,) the cost of operating the road after its construction will be minimum; both because its stations will be fewest and because the wear and tear of its rolling stock will be least.

The second plan reduces the prime cost of construction per mile of the road, but increases its length, and introduces curves, which are disadvantageous both by increasing the cost of maintenance and retarding the rapidity of movement. The increase of length may be more or less nearly an offset to the diminution of the original cost of a given length; so that, on this side, the saving may be more in seeming than in fact; but, at any rate, the increase in the cost of working and maintenance is very real; so that here the seemingly and possibly really cheaper road will prove in the end to be the most expensive.

As to the third plan, that of pursuing a nearly direct line with as little cutting and filling as possible, and replacing deep cuts and heavy fills by steep gradients, it keeps down the prime cost of the road per mile without increasing its length, and without admitting troublesome curves; but, on the other hand, it makes it an impossibility for a given locomotive any longer to draw the weight of train which, on a level road, constitutes its regular charge. The maximum load which the engine can drag up the steepest grade, is its maximum load for the whole way. But on a well constructed road, in good condition, the resistance to traction is doubled on a rising gradient as low as twenty feet to the mile. There are few roads which have not, in some portions of their length, gradients of forty or fifty feet to the mile; and many admit them much higher. All such roads, therefore, employ engines which, upon a horizontal track, could take much heavier trains than those with which they are actually charged. It follows that these engines have, over the greater part of the route, a surplus power, which may, indeed, be economized by keeping down the steam, but which cannot be employed usefully.

The question naturally arises, might not this surplus be expended in accumulating a store of power in reserve, to be applied in subsequent aid of the engine over the difficult parts of the way?

Again, as it happens on these ordinary roads with inclined gradients that the inclination will usually be descending as often as ascending; and as a train will run down a gradient of very low pitch by the effect of its own unaided gravity, so that in fact not only is it necessary in such cases to shut off the steam from the engine, but even also to apply the brakes in order to prevent a dangerous acceleration, it may be further asked whether the immense living force which the train thus acquires on a descending grade may not in some manner be accumulated and saved, so as to be usefully employed in assisting to overcome the next ascent.

These are questions which Captain von Schuberszky has been making the subject of long continued study and experimental investigation;

and the result is the machine which is named by him the Mahovos. Having been commissioned by his government to visit and carefully examine the various European railways into the construction of which heavy gradients have been admitted, and having personally acquainted himself with all the particulars of economical interest relating to them, and satisfied himself of their serious disadvantages, he was led to turn his thoughts toward a possibility of a remedy. It first occurred to him to employ the force developed in the train on a descending grade by gravity, in compressing air, with a view to apply the elastic force of the air so imprisoned in overcoming subsequent ascents; but in this his success did not satisfy his hopes, and, as an alternative idea, he determined to try the principle of the fly-wheel.

The Mahovos, then, is a fly-wheel, or, more properly, a pair of fly-wheels, and nothing more. The peculiarity of these wheels is that they are singularly heavy. They are provided with an independent truck of their own, which is introduced into the train immediately behind the engine. The truck has three pairs of running wheels approaching each other very nearly by their circumferences. In the intervals between these wheels are placed two pairs of friction wheels resting immediately on them, as cannon shot are piled upon one another in a magazine; and in the interval between these rests upon their circumferences the large axis of the Mahovos; the huge fly-wheels themselves overhanging the truck upon the two opposite sides. This pyramidal structure is reduced in height and rendered more stable, by giving to the middle pair of running wheels a diameter considerably less than that of their neighbors, and the friction wheels are made of such size as to run close to each other without touching.

It is easy to understand now the effect of this arrangement. When the train moves, the running wheels impart motion to the friction wheels, and the friction wheels transfer this movement to the fly-wheels. The diameters of the wheels, and that of the axis of the fly-wheels where it rests upon them, are so related that a velocity of thirty kilometres (18.6 miles) in the train will generate in the circumference of the fly-wheel a rotary velocity of one hundred and forty-two metres (466 feet) per second; and as the fly-wheels themselves weigh 26,000 kilograms (say—26 tons) it is computed that, with this velocity, they will embody a living force of more than twenty million kilogrammetres, or one hundred and forty-four million foot-pounds.

In order that this great velocity in a mass of such magnitude may not cause the bursting of the wheels by centrifugal force, the material used in their construction is cast steel; and Captain von Schuberszky asserts that they may safely be run five times as fast as any similar wheels constructed of cast iron. The casting of the massive perimeters is not made in a single ring. Apparently, from the description, they are fashioned somewhat as Mr. Krupp constructs cast-steel tires, viz., by splitting an ingot in the middle, opening it out and bringing it to the circular form

by hammering and rolling. Three separate rings thus formed are shrunk on to each other, the surfaces in contact having corresponding concavity and convexity to secure firm connection without the use of bolts. The axles of the fly-wheels, where they rest on the friction wheels, are protected by steel rings, in order to admit of renewal after wear without a change of the axle itself.

The friction wheels are also made of cast-steel, or of cast-iron with steel tires. Their surfaces are somewhat rounded like the band wheels of a lathe. In order to afford relief against sudden shocks, the axes of the extreme running wheels have boxes which yield to a slight extent horizontally, being backed by compacted rubber.

The effect of atmospheric resistance to rotation is reduced as low as possible by applying flat plates of iron to the lateral surfaces, which plates are secured in place by angle-iron, thus shutting in the spokes and making of each wheel a kind of drum. And as a security against accidents from the contact of persons or things with the wheels while in rotation, they are further enclosed within sheet iron boxes which serve as shields.

As the train moves from rest the velocity of the fly-wheels is gradually accelerated, and it attains finally a maximum which corresponds to the maximum velocity of the train. If now the steam is shut off from the engine, the fly-wheels themselves become a source of driving power, and they will maintain the movement until they have given back the work stored up in them precisely as it was at first received. But suppose it to be desired to stop the train without expending the accumulated force; this may be effected by a mechanism which allows the friction-wheels to be raised out of contact with the driving-wheels, while the fly-wheels continue to revolve without interruption. In stopping for brief intervals at stations, there is thus not only no material loss of power, but in starting anew it is not necessary to expend force in again putting the fly-wheels into motion. But when the stop is to be for a length of time, the steam may be shut off at a distance before reaching the station, such that the force of the machine may suffice to carry the train to the end and exhaust itself in the process.

In illustration of the advantages to be derived from the use of this contrivance, Captain Von Schuberszky considers the case of a freight train drawn with a maximum velocity of thirty kilometers, or say nineteen miles, an hour, by a locomotive of forty tons, with all its wheels coupled as driving-wheels. The resistance of the train on a level being taken at 0.004, and the force of traction at one-sixth the weight on the driving-wheels of the locomotive, we have, for a train whose weight is M, and a locomotive whose weight is m, running on a road whose maximum gradient is n, the equation—

$$\frac{p}{6} = \mathrm{M}\,(0.004+n).$$

Supposing the value of p to be forty tons, and the maximum gradient

one in a hundred, or say fifty-three feet to the mile, we shall find the value of M, or of the heaviest load which the locomotive can draw up the grade, by making these substitutions, thus:

$$6.667 = M\,(0.004 + 0.01),$$

whence,

$$M = 476.143 \text{ tons.}$$

But though this is a load to which the engine is equal under favorable circumstances, a considerable allowance must always be made for the possibilities of contrary winds, a track obstructed by snow, &c., &c., or for the occasional imperfect adhesion of the driving-wheels to the rails in consequence of moisture or ice. It is not considered safe to charge an engine with a load beyond about eighty per cent. of what it might perhaps carry through safely nine times out of ten, since the inconvenience and confusion which would be caused by the failure in the tenth instance would far overbalance the advantage gained by carrying a heavier load the nine times preceding.

The maximum allowable weight of a freight train on a road of maximum gradient of fifty or fifty-five feet to the mile, is then to be taken not higher than three hundred and eighty tons, in which weight the locomotive is included.

If, nevertheless, to such a train we add the Mahovos, of which the weight with that of its truck amounts to forty tons more, we shall not incur the liability to delay or stoppage which such an addition to the weight of the freight cars would occasion, since this machine itself carries with it a provision for preventing such accidents. If the rails are slippery in any place, and the adhesion of the driving-wheels of the engine is insufficient to maintain the movement, the wheels of the Mahovos supply an additional driving power equal for the time to that of the engine, so that the train will move with half the ordinary force of adhesion. It would be possible, therefore, to carry up the weight of the train to four hundred and fifty or four hundred and sixty tons by adding thirty or forty tons more of freight cars, and still incur no serious danger of stoppage.

The stoppage in such a case, should it occur, will occur probably on the inclines. If the weight of the train is not increased above four hundred and twenty tons it will be possible for it to ascend an incline steeper than that which has been supposed; that is to say, steeper than fifty-three feet to the mile, or one in a hundred. For since, on the incline, if, as usual, it is not of great length, both the engine and the Mahovos may be applied as motors, there will be twice as much power of traction as in an ordinary train, or in all an adhesive force represented by $6.667 \times 2 = 13.334$ tons. From this we may still make the deduction usually made as a security against accidents, of twenty per cent. of the power of traction of the locomotive, viz: $6.667 \times 0.20 = 1.3334$, and there will remain, notwithstanding this, the large available total of twelve tons. For short ascents the living force of the train itself may

be counted on as a help; as in fact, in actual practice, it often is by skilful engineers. This at the velocity of thirty kilometres, or 18.6 miles per hour, (8.265 metres, or 26.327 feet per second,) will give a living force in a train of four hundred and twenty tons, amounting to 1,462,600 kilogrammetres, or 10,565,000 foot-pounds, which is more than the fifteenth and less than the fourteenth part of the living force of the Mahovos as given above, and will therefore add in effect about 0.4 of a ton to the power of traction. The total power of traction will then be 12.4 tons, and the inclination of the gradient up which it will drag the train may be found by resolving, with respect to n, the equation,

$$12.4 = 420\ (0.004 \times n).$$

The resolution gives $n = 0.0255$, which is equivalent to a gradient of one hundred and thirty-five feet to the mile.

The next question is, how far will the accumulated force drag the train up such an incline as this? And here it must be remembered that the locomotive itself will take the train up a gradient of 0.012; so that the accumulated force will only have to contend against the excess of the gradient 0.0255 above this; that is, against an incline of 0.0135. This represents the ratio of the resistance of the train to its absolute weight, and consequently the total constant resistance is equal to $420 \times 0.0135 = 5{,}670$ kilograms.

On the other hand we have—

	Kilogrammetres.
Living force of the Mahovos	20, 875, 250
Living force of the train	1, 462, 590
Total	22, 337, 840

Hence, if D be the distance to which the train will be carried up an incline of one hundred and thirty-five feet to the mile throughout its whole extent, we shall have—

$$D = \frac{22{,}337{,}840}{5{,}670} = 3{,}922 \text{ metres};$$

that is, nearly four kilometres, and about two miles and two-fifths.

This, however, would exhaust the force entirely. If we consider it expedient to retain an ultimate velocity of nine and a half kilometres, or say six miles per hour, the available living force will not exceed 20,000,000 kilogrammetres, which will give—

$$D = \frac{20{,}000{,}000}{5{,}670} = 3{,}527 \text{ metres};$$

or three and a half kilometres, equal to two and a sixth miles.

On a grade of which the mean inclination is one hundred feet to the mile, or 0.019, the distance passed over in reducing the velocity of the train to six miles an hour would be nearly seven kilometres, or four and a quarter miles.

In leaving a station upon a level track the excess of power in the engine operating on the fly-wheels will bring up the living force to

about half its maximum in going two kilometres, or a mile and a quarter. This will correspond to the mean velocity of the train taken at twenty kilometres, or twelve and a half miles per hour. To bring it to the maximum, the train must move over two and a quarter times this distance.

Supposing successive grades of ascent and descent to be encountered, it is evident that as in the ascents the living force of the Mahovos is diminished by gravity, so in the descents it is increased. And since, on any descending gradient exceeding 0.004, or twenty feet to the mile, the train will run down itself, so that in ordinary practice it is not only necessary to shut off the steam, but likewise to put on the brakes, this machine, by absorbing the force usually wasted on the brakes, becomes a means of storing up the force of gravity itself; so that on a regularly undulating road on which it should be introduced, the engine would be required to do no more work than on a level. Moreover, in preventing without the use of brakes the train from acquiring an excessive velocity on a downward grade, it saves much wear and tear of rolling stock, and does away with the necessity of employing an army of brakemen upon every train.

In approaching a terminal station the fly-wheels may be allowed to expend their living force entirely. Supposing them at a maximum velocity and the track to be level, steam may be shut off more than thirteen kilometres, or eight miles before arrival. As this, however, would reduce the final velocity too far, it is best to shut off steam at about six miles before arrival, and to apply the brakes at the end.

At intermediate stations it is estimated that the Mahovos will lose, by friction on the axles of the supporting wheels, 80,000 kilogrammetres, or 580,000 foot-pounds of living force, every minute. Supposing the stop to continue ten minutes, there will be a total loss of 800,000 kilogrammetres, or 5,800,000 foot-pounds, which is only about two per cent. of its maximum amount.

In starting anew, the machine must be sustained out of contact with the driving wheels until a velocity has been acquired in the train corresponding to that which belongs to the rate of motion of the fly-wheels at the time, and must then be put again into connection with the running wheels. Should there be a discrepancy of rates between the train and the Mahovos, the running wheels will slide for a short distance on the rails; but it is easy to contrive indicators attached both to the wheels of the locomotive and to those of the Mahovos, which shall show their relative rates; and which, being both under the eye of the attendant, shall inform him when it is proper to make connection.

There is one use of the Mahovos which the inventor presents as capable, under certain circumstances, of being highly advantageous. It has been shown how this contrivance may be employed to fulfil the function of a brake on a descending grade. But, by the aid of an additional attachment brought into use only on extraordinary emergencies, it may

be made to act with great power as an instantaneous brake. For this purpose, on the axes of the friction wheels which sustain the Mahovos, there is a second pair of wheels somewhat smaller, and nearer the middle, which ordinarily run out of contact with anything. But the axis of the Mahovos above them carries a pair of eccentric rings, running loose upon it, which, when turned with the thicker part downward, wedge themselves, as it were, between the wheels above spoken of and the axis of the Mahovos, lifting the latter out of contact with the friction wheels.[1]

If the eccentrics can move no further, the fly-wheels continue to turn freely in them, but they no longer drive the running wheels of the truck. On the contrary the whole weight of the fly-wheels rests, through the eccentrics, as a brake upon the running wheels, and prevents them from turning at all. The force which the Mahovos thus opposes to the movement of the train is the sixth part of its own weight; and if the engine be reversed at the same time, and the brakes of the tender be put on, the total force of the resistance will amount to 16,667 kilograms. If the train is moving with a velocity of eight and a quarter metres per second, which is the assumed maximum, this is sufficient to carry it directly against gravity to a height expressed by h in the equation

$$h=\frac{v^2}{2g}=3.54 \text{ metres.}$$

v being the velocity of movement, and g the force of gravity, represented by 9.808 metres.

But the resistance 16,667, is only the twenty-fifth part of the weight of the train, and hence the living force in the moving mass would carry it twenty-five times as far against this resistance as against gravity. In other words, after the application of the Mahovos brake, the train would stop in 3.54 metres multiplied by twenty-five.

$$3.54\times 25=88.5 \text{ metres}=290.28 \text{ feet}=100 \text{ yards nearly.}$$

The train can thus be stopped in twenty seconds, an important advantage in case of any suddenly perceived misplaced switch, open draw-bridge, or obstruction on the track.

The presumed advantages of the employment of the Mahovos are briefly summed up as follows:

1. Diminished cost of ways in consequence of the admission of steeper grades than are now allowed.

2. Reduction of the amount of curvature and increase of the minimum radius, by which the mean velocity of movement may be improved and wear and tear diminished.

[1] The manner of effecting this change is very simple. The two eccentric rings are connected with a heavy weight in the form of a cylinder, extending from one to the other parallel to the axis of the Mahovos, and attached to the thick side of each. This weight is sustained on a level with the axis, or higher, by a support which admits of being instantaneously withdrawn. The heavy cylinder then falls, and by its mere weight wedges the rings beneath the axis of the Mahovos, with the consequence described in the text.

3. Since the original construction of the substructure is simpler, the cost of maintenance will be less.

4. As the rails and the wheels are less frequently subjected to wear by the brakes, they will be more durable.

5. The use of the Mahovos as an instantaneous brake may prevent grave accidents, such as are often attended with destruction of property and loss of life.

6. Economy of fuel is greatly promoted by the use of this auxiliary to the engine.

The account here given of this invention has been extended beyond the original intent, because, on an examination of its principles, it has seemed to embrace the germ of a real improvement. At first view, the impression produced by it was decidedly unfavorable; and it seemed as if the burden it would impose on the motive power would be more than an offset to the benefit it could render. Careful study has removed this impression and produced the conviction that the invention is capable of being made very substantially useful.

The question how great or how small may be its real value will not, however, long remain a matter of conjecture. It has already been tried by the inventor on the railroad from St. Petersburg to Warsaw; where, as he asserts, the fact has been practically established that, with its help, a double train can be carried the whole way. In Russia it has attracted flattering attention from railroad engineers and railroad directories; and a company has been formed under the presidency of Baron von Delwig, inspector general of all the Russian private railways, for the purpose of thoroughly testing its value in practice.

In the Exposition the Mahovos was illustrated by a very pretty model, which descended an incline of four to the hundred, for a distance of one or two hundred feet, the fly-wheels absorbing the force of gravity in the descent; and then after being reversed on a turn-table, dragged its train again to the top. The train was made up of box cars or tanks loaded with water.

The agent in attendance handed to visitors a card, which was probably not prepared by the inventor, containing the statement that the machine after descending the plane and being reversed on the turn-table, "would easily draw the train to the top of the same incline, still preserving much velocity in the fly-wheels, even though a man should mount upon the cars." This was saying more for the Mahovos than the inventor claims; and yet the result, which seemed to surprise nobody in the wise looking crowd which daily gathered to witness it, bore out the assertion. The Mahovos took the train to the top, and took the man also. In seeking for the solution of this phenomenon, it was presently perceived that in the descent of the train, the attendant followed it, and added to gravity all the force he could exert by pushing it from behind. The source therefore of the excess of power which the machine still preserved, after ascending the plane and carrying up the man, was no longer a mystery.

CHAPTER V.

MEASURE OF FORCE.

MECHANICAL CONTRIVANCES FOR MEASURING THE FORCE OF PRIME MOVERS—PRONY'S FRICTION DYNAMOMETER—TAURINES'S DYNAMOMETER—METHOD OF REGISTERING ITS INDICATIONS—BOURDON'S DYNAMOMETER—HIRN'S PANDYNAMOMETER—TORSION OF DRIVING-SHAFTS—THE DISTORTION OF PARTS OF MACHINES MADE TO INDICATE THE AMOUNT OF STRAIN—TWO METHODS OF ACCOMPLISHING THE RESULT; THE MECHANICAL AND THE ELECTRICAL—IMPORTANCE OF THIS INVENTION TO THE MECHANICAL ENGINEER.

DYNAMOMETERS.

Mechanical contrivances for measuring the force exerted by a prime mover, or the amount of force consumed in driving a machine or all the machines of an industrial establishment, have been constructed in various forms. They involve generally the expedient of interposing between the motor and the machine, as a medium through which the power is to be transmitted, some combination of springs, or some mechanism of which springs are the essential parts, provided with a scale on which are marked the degrees of static force corresponding to different states of tension, and sometimes also with automatic machinery for making periodical record of the marking of the index on the scale. Many of these contrivances have been long in use and are sufficiently familiar, and every Exposition brings forward one or two more.

PRONY'S FRICTION DYNAMOMETER.

Simpler than any of these is the friction brake of Prony; and but for certain disadvantages necessarily attendant on its use it would possess a superiority from which no other contrivance could displace it. This contrivance, as is well known, is unadapted to the measurement of a power which is at the same time usefully employed. In other words, it is unsuited to the determination of a force which is actually transmitted to a machine; it can only measure one which is generated in circumstances as nearly similar to those in which the machine is operated as by the most careful precautions they can be made; and this force is then assumed to be equivalent to the former one. The Prony dynamometer cannot be employed for the purpose desired without loss of time, and without the expense attendant on an unproductive application of power. Moreover, when motors are of great magnitude, the heat developed by the friction of the brake, and the rapid wearing away of the material, make it impossible to protract the experiment sufficiently to obtain

results entirely satisfactory. With such motors, also, there are dangers of accident from irregularity of movement, the consequence of the elasticity of the parts intervening between the motor and the brake, which may sometimes be attended with serious consequences. A dynamometer, on the other hand, which serves only as a medium of transmitting force without consuming it, and which, without occupying an inconvenient amount of space, may be permanently attached to the machine, will possess the very great advantage of showing the expenditure of force at all times, without requiring any special attention from the engineer or other attendant. It is to be desired that such a contrivance shall not be itself a charge upon the power; that is, that by its interposition the expenditure of driving force required shall not be sensibly increased. This property belongs to all that class in which the power of the motor acts directly with all its force to produce flexure in springs, while the springs by their effort of recoil transmit it undiminished to the machine. It is evident that there must be a limit to the applicability of this principle which will very soon be reached. As the power to be transmitted is made greater, the strength of the springs through which it is transmitted must be correspondingly increased. But this involves the necessity of making them heavier in similar proportion, so that they may soon become unwieldy and undesirable attachments to the moving parts of a machine. This objection may to a certain extent be evaded by giving to the springs such a form and such a position in the apparatus that the force of the motor shall be exerted mainly against their power of resistance to extension or compression, and only partially against their elasticity. Thus, if we give to a bar of tempered steel the form of a horseshoe, the force required to change its curvature by a definite amount, applied in the direction either to straighten it or to bend it still more, would be greatly less than would be necessary to produce a similar degree of change in the form of the same bar on supposition that it had the original shape of an archer's bow. Dynamometers, therefore, which are designed to transmit force on the principle here considered, allow the force to act wholly in producing flexure only when it is small; those designed for use in connection with steam-engines or other motors of considerable power being constructed in such a manner that the elasticity of the springs acts at a mechanical advantage.

TAURINES'S DYNAMOMETER.

A dynamometer of this kind was exhibited by Mr. Taurines, of Paris, which was simple and well adapted to engines of moderate power. It forms, if desired, a permanent part of the connection between the engine and the machine driven; and in this case the shaft of communication is constructed with a joint formed by inserting one length within the other, in the manner of tenon and mortise. Two arms are attached to the part of the shaft on either side of this joint, in a radial direction; those on the same side being diametrically opposite to each other, while those

of each pair are ninety degrees from those of the other. Stout springs in the form of circular quadrants connect the extremities of these arms on two opposed quarters of the circle, and the force of the motor is transmitted through these springs by a pushing effort. The effect is to bend the arches outward, and the degree of this bending is indicated by a spring which connects their middle points. The flexure of this spring is diminished, and in straightening it moves an index in the direction of the axis of rotation.

Mr. Taurines has added a very ingenious mode of registering the indications of the dynamometer, and, generally, of summing up the total amount of work done, (or, rather, of force transmitted from the motor,) during a continuous period of operation. This is, in fact, a modification of the planimeter of Oppikoffer, elsewhere described. The motion of the dynamometer index parallel to the axis of rotation is magnified and transferred, by suitable mechanical arrangement, to a little car running on a railway. This car sustains a solid cone, rather acute, and placed in such a position that one of its generating lines is horizontal. This cone is kept in rotation by the machine, with an angular velocity the same as that of the motor shaft, or definitely related to it. On the horizontal side of the rotating cone rests a little sphere, which is held between the two arms of a fork, being immediately sustained by two small caps, with spindles attached, like the stems of acorn cups, which serve as axes of motion. The sphere turns on the cone by friction, and its rotations are transmitted by one of the little axes just spoken of to a set of register dials. As the energy of the transmitted force increases or diminishes, the car moves forward and backward along its track, presenting to the sphere resting upon it a larger or smaller circle of contact. While therefore the velocity of rotation of the cone is constantly the same as that of the motor shaft, or in an unvarying ratio to that velocity, the rotation of the sphere is accelerated as the base of the cone is brought more nearly beneath it, and retarded as the vertex approaches. It is evident that a roller with a rounded periphery would answer as well as a sphere, the object being only to obtain a contact which shall be virtually a point; but, as by constantly running on the same circumference the surface of contact would be enlarged, a sphere is used so sustained that the longitudinal motion of the cone may give it a compound rotation, and thus change continually the circumference exposed to wear.

This dynamometer, when constructed with a view to be displaced and attached to other machines, will have, of course, proper connections by which its two opposite parts may be secured to the corresponding shafts of the motor and the machine operated upon.

A connection of this kind might suffice for steam-engines or other motors of moderate horse-power; but it is obvious that a limit to its availability must be soon reached, so that for motors of great energy no spring dynamometer will serve. The only expedient which presents itself, therefore, under these circumstances, seems to be to connect the

motor with the machine through some intermediate gear work, and to devise some method by which the effort passing through this gear work may be measured.

BOURDON'S DYNAMOMETER.

Such a dynamometer is exhibited by Mr. Bourdon, of Paris, which may be briefly thus described. Parallel to the direction of the shaft of the motor are established two other shafts, each carrying a gear wheel, by which they act on each other. One of these shafts is connected by band or gearing with the motor, the other transmits the movement similarly to the machine. The shaft connected with the motor is capable of no motion except that of rotation; the other has a certain freedom of displacement in its bearings, longitudinally. The teeth of the two gear wheels are slightly spiral. The effort of the motor tends not only to turn the movable arbor, but also to displace it in the direction of its own length. If no resistance were opposed to this displacement, it would immediately find its limit, and the arbor would then have only a rotary motion. The displacement, however, is opposed by a spring, and it takes place only so far as to bring about a condition of equilibrium between the resistance of the spring and the element of the driving force which is directed longitudinally. The value of this element will depend upon the degree of obliquity of the teeth of the spiral gearing to the axis of rotation. If their surfaces are parallel to the axis, there will be no longitudinal displacement. And whatever be the angle of inclination, the longitudinal force will bear a calculable and constant ratio to the total force exerted by the motor, so that by measuring this fraction of it we in effect measure the whole. A scale must be adapted to a dynamometer of this kind by a series of experiments, in which static forces of torsion may be substituted for the action of a motor.

The dynamometer of Mr. Bourdon is founded on a principle which was, it is believed, first employed by an American inventor—Mr. Neer, of New York—in an instrument of this kind patented by him ten or twelve years ago, and exhibited at the Exposition of 1862, where it was honored with a medal. In this the wheels or pulleys of the dynamometer were upon the same shaft, one being fixed and the other free; and the displacement of the loose pulley took place in consequence of the action of fixed arms upon the other, acting upon inclined surfaces upon its opposed face. It had also an automatic registering apparatus, a very important addition to such an instrument, and one which is almost indispensable to its usefulness in practice.

HIRN'S PANDYNAMOMETER.

The most ingenious form of dynamometer which has ever yet been presented, is one which was exhibited at the Exposition of 1867, by Mr. G. A. Hirn, of Logelbach, on the Rhine, and called by him, from its universal applicability, a pandynamometer. It is founded on the idea of making the machine itself, of which the performance is to be tested, the

instrument of measuring its own work, through the distortion produced in it by the transmission of the driving power.

Whenever a force which originates at one point is applied at another, to the overcoming of resistances by means of any system of solid connections, these solids must necessarily, for the time being, change their form. When, as is usually the case with powerful motors, the transmission is made by means of a revolving shaft, the shaft will undergo torsion to an extent proportional to the resistance which opposes its revolution; and if this torsion can be measured, it may be the means of measuring the power of the motor itself. This is what the pandynamometer of Mr. Hirn proposes to do.

Previously to observation, it might seem impossible that the massive iron shafts used to drive the machinery of foundries and factories, or the helices which propel our great ocean steamers, could possibly change their figure sufficiently to answer the purposes of the proposed determination; but when the question is subjected to the test of careful experiment, it is demonstrated that the torsion of the strongest shaft, under the great strain to which it is subjected, is a quantity quite measurable.

It is of course desirable that the indications of the dynamometer should be as large as possible, and therefore in applying the principle of Mr. Hirn, and making the machine tell its own story, it is best to select upon the shaft whose torsion is to be measured, two points as far apart as convenience will allow. To these parts are adapted pulleys or gear-wheels, which are designed to operate a recording apparatus which serves to register, periodically, the condition of the shaft as to torsion. In order that these wheels may be attached without in any manner disturbing the arrangements of the machine, they are constructed in halves so as to be applied on opposite sides of the shaft and bolted together. It would be impossible, without detailed drawings, to describe the exact manner in which Mr. Hirn proposes to obtain the indications desired. He has two independent modes, in fact, in which he accomplishes the object; one of them being mechanical and the other electrical. Without, however, explaining his actual process, it is easy to illustrate the possibility of obtaining the proposed result on either of the two principles. Let, for example, a metallic cylinder covered with paper suitably prepared for the purpose by chemical means, be kept in rotation by the motor, and let the end of an insulated metallic wire rest upon the surface of this paper, while the other end is connected with one pole of a battery. Let connection also be made between the metal of the cylinder and the other pole. If with these arrangements the battery is supposed to be charged, the wire will trace a visible line upon the paper. If we now cut the wire and carry its divided extremities to the axis of the motor at one of the points fixed on for observation, and if we there attach an insulating band to the axis itself, and over this apply a narrower metallic band on which one of the wire ends may rest as a tangent while the other is made a similar tangent to the portion of the non-con-

ducting substance which the metal does not cover, then all that is necessary to cause the circuit to be closed at every revolution of the shaft, is to introduce into the non-conducting ring a very narrow strip of metal in contact itself with the metallic ring. As this slip passes under the tangent wire last mentioned, the circuit will be for an instant complete, and a dot will be made upon the chemically prepared paper. Now suppose that the wire which rests on the paper has two branches by which it communicates with the battery; and let the second branch be treated as we have supposed the first to be; only that the two ends formed by cutting it are carried to the second point of observation on the shaft; and let the arrangement of the rings on the shaft be such that when there is no torsion, or when the shaft is turning without resistance, the two contacts shall be made simultaneously. It is evident that there will be but one mark produced upon the cylinder. If, however, the axis is twisted by the effort of the motor and the opposed resistance of the machine, the contact at the end near the motor will take place first, and that near the machine after a minute interval which will depend for its value upon the amount of torsion. Instead of a single spot therefore upon the paper there will be two spots; and the distance between them will furnish an indication of the force which is being at the time transmitted through the shaft. It may be observed that the distance of the two marks from each other in angular space may be magnified by giving to the cylinder which receives the record a velocity of rotation exceeding that of the working shaft. Or a mechanism may be attached to the shaft which shall gradually accumulate the values of the successive intervals for many successive revolutions, and shall indicate the result by marks occurring, for example, at the end of every fifty or one hundred. This last is the method employed in fact by Mr. Hirn, the actual record made by his machine multiplying the actual torsion fifty times. It is easy to see how a mechanical mode of registration might be substituted for the one which has been described. Without attempting to give Mr. Hirn's construction, which is not that here suggested, it may be simply observed that if, instead of bands attached to the shaft for the purpose of producing periodical electrical contacts, we suppose cams of what is called the snail-form to be substituted, two springs resting on these cams so as to fall simultaneously in the absence of torsion, would fall successively when the shaft is twisted; and the mechanical force exerted by such springs might be made to determine the simultaneous fall of marking points upon the revolving cylinder. It is only to be added, that, in case a record of the performance of the motor is to be maintained for a length of time, the cylinder of record, or the marker itself, should receive a movement of gradual translation in the direction of the axis of motion; an effect which may be easily produced by a suitable adaptation of a simple or combination screw. It remains only to find the absolute value of the indications of the record, or the unit of value of the scale. For this purpose, when the machine is at rest, arms are attached to the shaft

at right angles to the axis, and at points embracing between them the two points of application of the dynamometric apparatus, the two arms being in one horizontal plane and on opposite sides of the axis. From these arms are suspended scale-platforms which are loaded with weights gradually increasing, while the amount of torsion corresponding to each weight is directly observed. In deducing values for practical use in calculation, the weight of the arms and the attached scale-platforms must be considered and reduced to its equivalent supposed to be applied at the point of suspension.

It is believed that this invention not only possesses the merit of entire originality, but that it is also a very important addition to the resources of the mechanical engineer. It has already been tested in many cases with results entirely satisfactory.

CHAPTER VI.

DIRECT APPLICATIONS OF FORCE.

Machines for the elevation of water—Valve pumps—Earle's steam-pump—Schabaver & Foures's pump for the elevation of water, sand, and gravel—Perreaux's pumps—Antodymanic elevators—Champsaur's—Reynolds's water jet elevator—Rotary pumps—Centrifugal pumps—Gwynne & Co.'s centrifugal pump—Neut & Dumont's—Coignard & Co.'s—Coignard's helicoidal pump—Andrews's centrifugal pump—Girard's turbine elevator—Blowing machines—Lloyd's noiseless fan—Schiele's compound blowing fan—Evrard's rotary compression blower—Root's blower—Thirion's hydraulic pressure blower—Hydraulic presses—Challet-Champion's hydraulic press—Desgoffe and Ollivier's sterhydraulic apparatus—Apparatus for testing the tenacity of wire—Ascenseur Édoux—Hydraulic counterpoise—Girard's palier glissant—Mechanical presses.

I.—HYDRAULIC ELEVATORS.

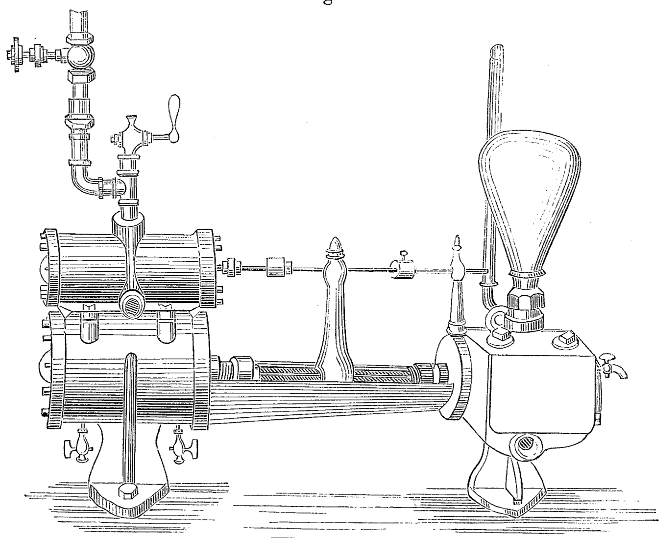
Tne number and variety of machines for the elevation of water present in the Exposition was very great. Every form of pump known had its representatives. The larger number of these were without originality of construction, though many of them were quite worthy of consideration for their cheapness or creditable workmanship. A few only have any particular claim to be noticed for novelty or improved efficiency.

VALVE-PUMPS.

EARLE'S STEAM-PUMP.

An American steam-pump which, for its simplicity and steadiness of

Fig. 40.



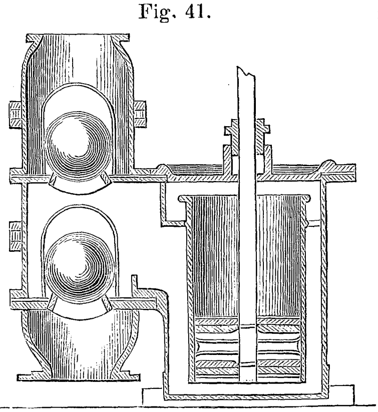
Earle's Steam-pump.

action, attracted a great deal of attention, was exhibited by Messrs. G. Dwight, jr. & Co., of Springfield, but was understood to be the invention of Mr. Oscar T. Earle, of the same place. This is a horizontal pump in which the pistons in the steam cylinder and water cylinder are attached to the same rod. The peculiar merit consists in such an arrangement of the steam valves as to produce a perfectly smooth movement, and to allow the pump to be started in any position of the piston. The valves, or apparatus for steam distribution, are contained in a cylinder immediately over the steam cylinder, and the movement of the slide is effected by means of an upright arm carried by the piston rod. The figure here given represents this arrangement. An air vessel immediately over the cylinder of the pump regulates the pressure of the ascending column. The necessity of a fly-wheel is obviated by the peculiarities of the steam distribution just mentioned, which could not be described intelligibly without the aid of sectional views. Access to the interior for the purpose of making repairs or adjustments is easy, and the small number of parts, the general simplicity of construction, and the compactness of the whole, are strong recommendations.

SCHABAVER & FOURES'S POMPE CASTRAISE.

A pump, called the *pompe castraise*, exhibited by Messrs. Schabaver & Foures, of Castres, designed for elevating water containing sand or gravel, was distinguished by some remarkable peculiarities. A single cylinder is open both at top and bottom, and is traversed by a piston without a valve. The cylinder is enclosed in a larger vessel, water-tight, which is itself filled with water. This larger vessel is divided into two equal parts vertically, by a partition which joins the working cylinder, so that the cylinder itself forms a part of the division. One extremity of the cylinder communicates with the cavity on one side of the partition, and the other with the opposite. The valves are large balls of India-rubber, loaded in the interior with lead, and are kept in place simply by a kind of cage formed of curved straps of metal fixed over them. There are four valves. They are contained in separate boxes by the side of the principal box, and are in communication by pairs with the two cavities into which that box is divided. The figure given shows a section of the cylinder, and a view of the arrangement of the pair of valves corresponding to the nearer half of the cylinder reservoir. The piston is represented as at the bottom of the stroke. It is evident that, when it rises, the lower valve must be raised by aspiration, and a volume of water will be admitted equal to the capacity of the cylinder. When the piston descends the

Fig. 41.



Schabaver and Foures's Pompe Castraise.

lower valve will be closed by the pressure, while the upper one will rise and allow the water just admitted to be discharged. It is unnecessary to observe that the action of the second pair of valves corresponds to that of the first, as just described; so that the aspiration and the discharge are both proceeding, which ever way the piston may be moving. What constitutes the special merit of this pump is, that the water which is raised enters only partially the box which contains the pump cylinder, and is immediately driven out again, without coming into contact with the piston itself; so that the danger of obstruction or injury by the introduction of foreign matters is small. The caoutchouc valves also adapt themselves under the pressure easily to their places, notwithstanding that solid substances may sometimes be caught beneath them. This description of pump is therefore well adapted to the draining of marshes or of excavations where the waters bring along with them sand, leaves, or the debris of vegetation; but on account of its bulk and weight is not adapted to general use.

Experiments made on this pump at the *Conservatoire des Arts et Métiers*, show an efficiency of fifty-six per cent. of the motive power, which is superior to that of most centrifugal pumps, and equal to that of other good piston pumps. At slow velocities, the performance reached sixty-six per cent. The waste of water by leakage was estimated at from seven to ten per cent.

PERREAUX'S PUMPS.

Certain pumps exhibited by Mr. Perreaux, of Paris, presented a peculiarity in the form of their valves, which is designed to adapt them to the uses for which the *pompes castraises* are intended. These valves are formed of India-rubber, cylindrical at the bottom, but having a quasi conical figure ending in a wedge-shaped summit. This wedge is split so as to form two lips easily opened by pressure from beneath, but closed by pressure from above. It is easily seen that such a contrivance may serve effectually to prevent the return of water which has passed through it, even though foreign substances should occasionally lodge in the opening. A valve of this kind placed at the bottom of the cylinder, and another in the piston, suffice to form a lifting pump.

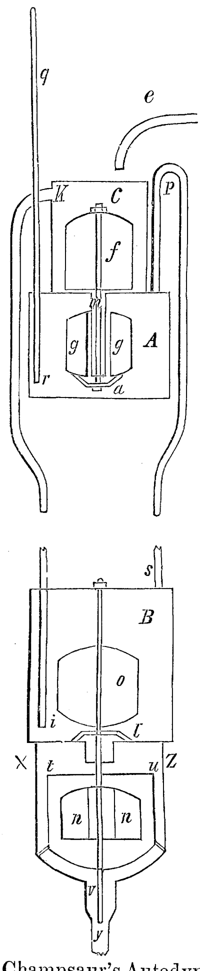
AUTODYNAMIC ELEVATORS.

CHAMPSAUR'S AUTODYNAMIC ELEVATOR.

A simple and very ingenious water elevator was exposed by Mr. Champsaur, of Marseilles, which is capable of being made very useful where, as for instance for domestic purposes, it is desired to raise a limited quantity of water per diem to a height of twenty or thirty feet. It is founded on the principle of the fountain of Heron, but is automatic in its action, and will continue to operate so long as the supply continues to be admitted from the source. Like the hydraulic ram, it elevates a portion only of the water which passes through it; but it is much supe-

rior to the ram in the amount of service rendered for a given expenditure. It is not, however, available in all situations, but requires that the waste water shall be discharged as far below the level of supply, as the portion to be utilized is to be raised above the same level. Wherever this condition can be secured, the contrivance cannot fail to be serviceable.

Fig. 42.



Champsaur's Autodynamic Elevator.

The operation of this machine can best be understood by reference to the accompanying figure, which represents it in section, and illustrates its principle without aiming to present the exact form. It is to be premised that the fountain of Heron consists essentially of two closed cavities at different levels, communicating by a tube which opens into the top of each. When the fountain is ready for operation, the upper cavity is entirely full of water, while the lower contains only air. Water is then admitted into the lower cavity from a superior level, by means of a tube which descends to the bottom of that cavity, and which entering drives out the air through the tube of communication into the cavity or vessel above. This air entering above the water in that vessel, exerts a pressure upon its surface; and if another tube be introduced, descending nearly to the bottom of the same vessel and open upwards, the water may be elevated through this tube to a height corresponding to the pressure exerted.

In the figure referred to, the upper cavity or vessel is marked A, and the lower one B. The connecting tube is *ps*, interrupted in the drawing in order to bring the important parts near to each other. The cylinder C, which surmounts A, and the cylinder *xyz*, beneath B, are necessary to the automatic action to be now explained.

Four floats, *f*, *g*, *o*, and *n*, are the principal means by which this automatic action is effected. The float *g* has a cylindrical opening through the middle, and it rests on *a*, which is a valve designed to close, at the proper time, the mouth of the tube *m*, which is fixed air-tight in the top of the vessel A, and is open at both ends. The float *g* is so adjusted in weight as to be just equal to an equal volume of water, so that when wholly immersed it tends neither to rise nor to fall. The float *f* is, however, buoyant in water, and it carries the valve *a* by means of a vertical rod or spindle.

It being presumed that the whole apparatus is full of air, water is supposed to be admitted from the source through the pipe *e*. This water, falling into the vessel C, will descend through the tube *m* into A, which will gradually be filled, the air contained in it being expelled

through the tube *ps*. A being filled, the vessel C will fill in its turn, and the float *f* rising will close the valve *a*. The level of the water in C having reached K, there will be an overflow through the pipe K*i*, and the vessel B will gradually fill. This vessel has also a valve in the bottom, marked *l*, which is connected by a stem with the float *o*. The weight of this float keeps the valve closed so long as B contains only air, and when the water enters, its downward pressure on the valve contributes also to maintain it in place. When the float is entirely immersed, it tends by its buoyancy to lift the valve; but its weight is so adjusted as to prevent any movement so long as the hydraulic head exceeds the height of the vessel A; that is to say, so long as the tube K*i* continues to be full. But as the water rises in B, the air is expelled through *sp*, and entering A, drives the water contained in that vessel upward through the ascending pipe *rq*. But it is obvious that the height of the point of delivery in *rq* cannot be greater than the height K*i*, otherwise water would cease to flow through the tube K, and the supply would overflow the vessel C, and run to waste. Practically, *rq* should be somewhat less in height than K*i*. Then supposing that the capacities of A and B are suitably adjusted to each other, the result will be that the level of the water in A will be depressed below the point *r*, and the compressed air will escape through *rq*. The pressure on the valve *a* being thus relieved, the weight of the float *g* will open the valve, and the water from C, entering again through *m*, will charge the vessel anew.

But B is now full of water which must be discharged. The pressure of the hydraulic head having been taken off by the removal of the pressure in A, and the fall of the water level in C, the float *o* lifts the valve *l* and the water escapes. But *l* must be kept open until B is entirely empty; and we have seen that the float *o* is heavy enough to close the valve unless it is entirely immersed, or nearly so. For this reason there are attached below B the two concentric cylinders *xz* and *tu*, the first and outer one having a discharge pipe *y*, and the second and inner having an opening *v* in the bottom which is insufficient to discharge the water as rapidly as it enters through the valve *l*. In this cylinder is placed a float *n*, attached to the same spindle which carries the valve *l* and the float *o*, and which is sufficiently buoyant, while *tu* is full of water, to keep both raised. In the first efflux of water from B, *tu* is filled, and the overflow from it is discharged through *y*. After B is entirely freed from its charge, the water remaining in *tu* escapes through *v*, and the valve *l* is closed once more. The process then recommences from the beginning.

The relative capacity of the vessels A and B will be determined by the height K*i* and the height of the point of delivery in *rq* above *r*. If the point *r* is taken at the maximum height possible, then the elastic force of the air in A will be equal to one atmosphere, *plus* the pressure due to the hydraulic head K*i*. Or, putting *p* for the natural pressure of

the atmosphere, p' for the pressure in A, and h for the value of the hydraulic head, we shall have $p' = p + h$. Assuming volumes to be inversely as pressures, as they will be nearly, since the heat developed by pressure will be principally absorbed by the water, then A should be to B, as p to $p+h$.

If h be represented by the height in feet of A above B, or rather of the volume Ki, p may be taken as equal to 34. Suppose $rq = 34$ also; and it would follow that B must be of twice the capacity of A. But if the height rq be less than the height Ki, it will be this height rq only which will determine the degree of compression to which the air in A will be subjected; and if we represent this height by h', we shall have,

$$p' = p + h'; \text{ and } A : B :: p : p + h'.$$

Put then

$$h' = 17, \text{ and } A : B :: 34 : 51;$$

Or A is two-thirds of B in respect of capacity.

It is thus seen that the amount of water expended in proportion to the amount lifted is greater as the lift is higher. The case is not like that of a balance, in which a descending weight raises another equal weight through an equal space. There, no waste of power occurs except what is due to impediments to motion; and hence the proportion between power expended and effect produced is the same whatever be the extent of the movement. The waste of force which occurs in this machine is that which is due to the compression of the air. No useful effect occurs until this compression is complete; but the water simply ascends in the pipe rq to a height increasing with the pressure. When the delivery commences, the pressure remains stationary; the compressed air serving merely as a medium for the transmission of force. Supposing h and h' equal therefore, the vessel B must be half filled with water before the useful effect begins. This measures the amount of waste. If h' is less than h, the delivery will commence when B is filled to an extent expressed by the fraction

$$\frac{h'}{p + h'}.$$

If there are any uses to which the waste water can be applied at the lower level, it need not be a total loss. In a hotel, supposing that the water supply reaches only to the second or third story, this apparatus may elevate a sufficient amount for the service of the higher floors, while the waste water may supply a laundry in the basement.

REYNOLDS'S WATER-JET ELEVATOR.

Among the recently invented forms of apparatus for the elevation of water, is one which, though it was not present in the Exposition, is entitled to mention here for its novelty. This is the ingenious water-jet elevator, invented by Mr. Edward Reynolds, engineer of the River Don Steel Works, at Sheffield, England, owned by Messrs. Vickers, Sons & Co. The power of a current of any fluid, liquid or gaseous, to drag

along with it the contiguous fluid through which it moves is well known. In Ewbank's Hydraulics, published thirty years ago, are described several forms of apparatus designed to produce exhaustion by the application of this principle. The practical application which Mr. Ewbank proposed to make of his inventions was to vacuum evaporation in the manufacture of sugar. Supposing the sirup to be contained in a vessel having the form of a still with a retort neck reduced to a small diameter, he introduced into the neck through one side a steam-jet, which was bent, after entering, at right angles, and made concentric with the neck itself, leaving but a small annular space between the two. Steam under very high pressure being then blown out of the mouth of the tube, the air contained in the still is blown out along with it, and a vacuum is produced which, as many of Mr. Ewbank's experiments proved, may become very nearly absolute.

Mr. Reynolds's invention is substantially the same, except that instead of steam he employs a jet of water under high pressure, and utilizes the vacuum produced for the purpose of raising water from a well; or in the present instance from a pit which it is desired to drain. An ascending tube from the water of the pit, which may be called the tube of aspiration, is bent into a horizontal direction at the level at which it is desired to discharge the water elevated, and through the lower side of this tube is introduced the jet, which is also directed horizontally in the interior, and made concentric with the aspiring tube. The aspiring tube is two inches in diameter, but immediately in front of the jet it is reduced to three-quarters of an inch; which reduced diameter is preserved for a length of three inches, after which the tube takes a flare and becomes, in a length of three or four inches more, of the original diameter again. The narrow part is called the barrel; the enlarged part beyond, the delivery pipe.

The diameter of the high-pressure pipe is one inch, but it is reduced at the jet to 0.15 inch, or about one-eighth of an inch. The jet is of brass; the rest of the pump is of cast iron. The water is raised from a depth of fourteen feet, and though there is no foot valve, the pump primes and starts itself. One precaution only is necessary to secure this result, which is that the delivery pipe should not be so short and straight that the jet may pass out without meeting with some retardation by striking against its sides. In any case, however, if a momentary obstruction be placed at the mouth, say by merely placing the hand over it, the barrel fills, and then the operation goes on indefinitely. To fill the barrel is the only necessity, and this might be done, apparently, by a priming from a funnel above, if the simplicity of the expedient just mentioned did not render such a complication useless. The experiments thus far made show a delivery equal to seventy-two per cent. of that theoretically due to the full quantity of water expended. This ingenious contrivance is still the subject of experiment, for the purpose of determining the largest useful effect under various conditions.

ROTARY PUMPS.

It is generally true of rotary steam-engines that they are capable of being used as hydraulic engines also, by substituting the pressure of a column of water for that of steam. And as it is by the descent of the column that the machine becomes a motor, so if a more powerful antagonist motor be employed to reverse the direction of revolution, it is obvious that the descending column will be forced to rise. Thus every rotary steam-engine is capable by reversal of being converted into a rotary pump. In fact this claim is distinctly made on behalf of all those which were exhibited in action in the Exposition, but only one of these was shown in operation as employed actually in the capacity of a water elevator. This was the engine of Behrens, exposed in the American department by Dart & Co., of New York. This machine and others of its class have been sufficiently described elsewhere.

CENTRIFUGAL PUMPS.

Pumps called centrifugal are rotary also, but their efficacy depends upon a different principle. The action of the one is a lifting and that of the other a throwing action. In the former case, therefore, the return of the column is prevented by close packing; in the latter by the superior living force of the mass put into motion at its base.

The invention of the centrifugal pump is ascribed to Appold, an English engineer. It was first brought to public notice in London at the Exposition of 1851. All the forms which have since made their appearance have been only modifications in detail of the original model; but while these modifications have in some respects improved the construction of the machine, or provided against causes liable occasionally to interfere with the regularity of its performance, they have not very sensibly improved its efficiency as measured by the relation between force expended and work done. A centrifugal pump may be compared to a ventilator receiving air at the centre and discharging it at the circumference. Or perhaps a better illustration may be found in a turbine water wheel which receives a liquid column descending along a hollow vertical axis; only that we must suppose the turbine in this case to be driven backward by another motor, so that the motion of the descending column is forcibly reversed. Or if we suppose the turbine to be enclosed in a water-tight box, open only beneath at the centre, while a larger water-tight box includes this one, with an upright tube ascending from it but not communicating with the water except through the interior of the turbine, then the turbine, being placed beneath the surface of the water and driven forward, will act as a centrifugal pump. The illustration first given is preferable, however, because it serves to show that the popular idea of this machine, derived from its name, is incorrect. The pump does not owe its efficiency to *centrifugal force*, any more than the ordinary compression or force pump does so. In the

first case supposed above, in which force is employed to drive a turbine backward, it is evident that a column may be made to ascend when the water pressure which lifts it is produced by a flow from the circumference toward the centre, but there would be no propriety in calling such a machine a centripetal pump.

There is no doubt, however, that the inventor and most of his imitators have always regarded the elevating power of the pump as due to the rotary velocity given to the water in its interior. The theoretic investigation of its properties has therefore been invariably conducted on this supposition; although experiment has made it manifest from the beginning, that the construction which that theory rigidly exacts as the condition of greatest efficiency, furnishes the most unsatisfactory results of all; results, in fact, so unsatisfactory that if no better could be obtained, the machine would be economically a failure, and would have to be abandoned.

GWYNNE & CO.'S CENTRIFUGAL PUMP.

The general construction of the centrifugal pump may be understood by reference to the figures of the machine of Gwynne & Co., of London, (Figs. 43–46,) the first of which shows a section perpendicular to the axis

Fig. 43.

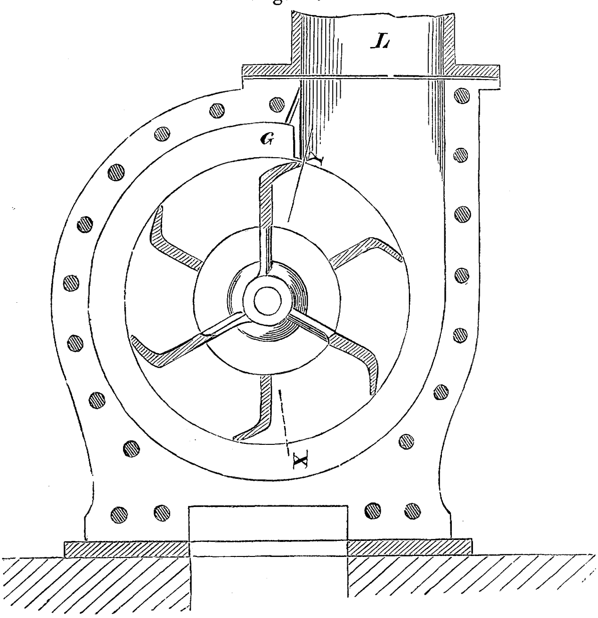
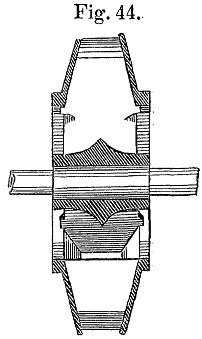


Fig. 44.



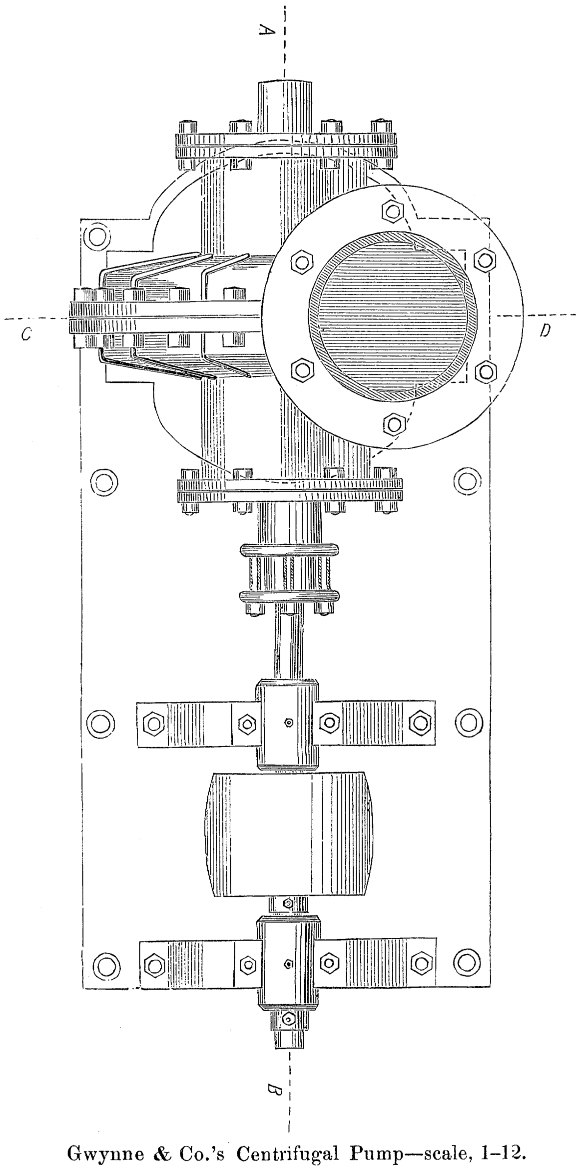
Section through X Y.

Gwynne & Co.'s Centrifugal Pump—scale, 1–12.

of rotation, and the last, Fig. 46, another section along the axis itself. In a circular (but not cylindrical) box there are fixed six equidistant pallets, straight at first and coincident with the direction of the radii, but inclined toward their outward extremities. The water is received at the centre on

each side of the box, and is discharged through the circumference, and afterwards through the ascending tube L. The limits of the centre of admission are indicated in the figure. Only three of the pallets originate at the axis itself. The other three extend toward the centre as far only as the circle of admission. The figure showing the longitudinal section shows also that the pallets are sustained by lateral walls. This figure is strictly in section only where the shading is oblique; the other shaded parts being beyond the surface of section. Thus, above and below the *hub*, through which the axis passes, are the open circles through which the water enters. The pallets, as seen in the larger figure, (43,) are rounded at the edges within this limit, in order that the influx may be as smooth as possible. The rotary apparatus is thus a box within a larger box, with which it is in contact only on two annular surfaces just at the circumference of the admission openings. The contact here must be as close as possible without serious frictional resistance. The revolving drum, as observed above, is not cylindrical. As the water moves outwardly from the central opening with a velocity always increasing, theory indicates that for a two-fold reason the breadth of each pallet parallel to the axis should diminish toward the circumference. For, first, if there

Fig. 45.

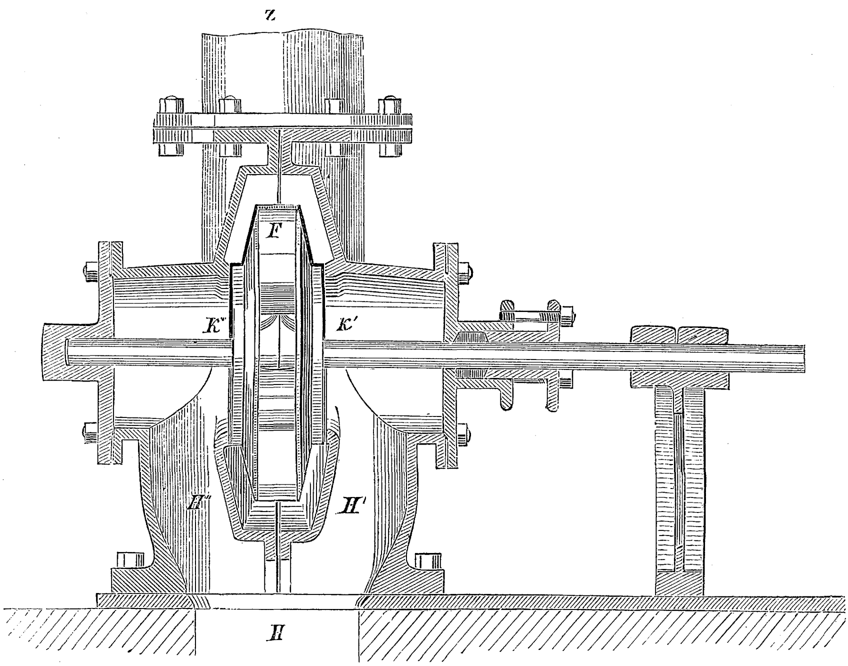


Gwynne & Co.'s Centrifugal Pump—scale, 1–12.

were no acceleration of movement, the superficial area of each concentric cylindrical section would have to be the same, which could only be made true by reducing its length in proportion to the increase of the radius; and in the second place, a proper provision for the real acceleration which is presumed to occur, would require an additional reduction. These are the indications of the centrifugal theory. Practically it will be obvious on the merest inspection of any centrifugal pump that they are carried out only partially. In fact, there is no need for attention to the second particular, since it is not in the least desirable that the velocity of the water in a radial direction should be accelerated. On the other hand, the condition of greatest efficiency in this particular will be satisfied by giving such form to the rotating apparatus that the same volume of liquid shall pass through every concentric cylindric section in the same time, and that the radial velocity shall be constant.

The general external appearance of the pump is shown in Fig. 45, where the form of the enclosing box is seen to correspond generally to the condition just stated, and where the position of the driving pulley on the axis of the rotary system is shown. Fig. 46 shows the system of pallets (shown in section in Fig. 44) in place, and also makes more clear

Fig. 46.



Gwynne & Co.'s Centrifugal Pump—section through the axis—scale, 1–12.

the manner in which the water is admitted. H is the pipe through which the water arrives from this source; H′ and H″ are sections of the two channels by which it is led to K and K″, the central openings by which it

enters the pump. One of the pallets appears at F. Between the rotary apparatus and the box which encloses it, is an annular space into which the water is driven by the motive power, and which is indicated in Fig. 43, beyond the limits of the pallets at G, and shown in section in Fig. 46. At Y, Fig. 43, is further observed a partition which shuts off this annular space from the ascending tube L. At G is also indicated a small opening from the annular space behind the partition to the tube L, which is designed to allow any air which may accidentally find its way into the pump to make its escape. In case the pump were to be wholly immersed in the water of supply, the presence of air within the box would be a matter of no practical consequence; but whenever, as will usually be the case, the water is to be raised to the apertures of admission by the aspiration of the pump itself, it is easily seen that air in any quantity, in virtue of its elasticity, may diminish the power of aspiration, and finally destroy it altogether, precisely as the action of a siphon is arrested by the accumulation of air in the bend.

Assuming the centrifugal theory to be the true one, the principles on which the efficacy of this machine depends may be stated as follows. By the rapid rotation of the pallets a similar rotation is imparted to the water enclosed within the box of the pump. If at any point of the circumference of the box a tangential tube, of no greater cross-section than the annular cavity G, should be attached, communicating with the interior, but not prolonged externally beyond what is necessary to clear the circular contour of the box, a stream would gush from it having the same velocity as that belonging at the moment to the water in the annular cavity. If now we suppose the tube to be prolonged upward and to receive successively different lengths, we shall find that while the height is small the water still flows with considerable velocity, but with a velocity diminishing as the height is increased.

At considerable heights the quantity of water delivered in a given time will become very small, and by careful trials we shall at length find a height at which (supposing the machine to be driven uniformly) the tube will stand permanently exactly full, but will deliver no water at all. Now, at any stage in the course of these experiments, by opening a stop-cock at the bottom of the column we shall find the velocity of efflux at that point entirely unchanged, and this velocity will be the same as is observed when no column is raised at all. Moreover, if after the water attains its maximum height and comes to a stand-still in the tube, we cut off communication with the pump, and by opening a stop-cock in the foot of the tube ascertain the velocity of the water issuing under the pressure of the column, we shall find it exactly what it was found to be while the communication with the pump was free. Now, it is a familiar truth in hydrodynamics that the velocity with which a liquid issues from an orifice in the containing vessel, in virtue of its own pressure, is exactly equal to that which a heavy body would acquire in falling freely from the level of the surface of the liquid to the level of the orifice of

escape. If then the height is given, the velocity may be found; and if the velocity is given, the height may be found. Putting h for the height, v for the velocity, and g for the force of gravity represented by the velocity which this force will impart to a falling body in one second from rest, (32.083 feet,) it is true that—

$$v^2=2gh;\ \text{or}\ h=\frac{v^2}{2g}.$$

To find h, the maximum height to which the pump may be presumed capable of raising a column, we want only therefore to ascertain the value of v, the velocity imparted to the fluid in the annular space G, when the number of revolutions per minute of the axis of the pump is known. What this velocity in given conditions ever actually is, could probably only be ascertained experimentally in the manner suggested above. But it is sufficiently evident that there is a limit which it cannot exceed, and that is the velocity of the outermost extremities of the pallets from which it receives its motion. This velocity may easily be computed when the number of revolutions and the distance of the extremity of the pallet from the centre of motion are known. Put n, for example, for the number of revolutions per minute, and r for the radius of the circle described by the pallet, and we shall have the space moved over per second, or the velocity sought, in the expression

$$v=\frac{2\pi rn}{60}=\frac{\pi rn}{30}.$$

$$\text{And } h=\frac{v^2}{2g}=\frac{\pi^2r^2n^2}{1800g}=0.0001705475r^2n^2.$$

Mr. Appold, the inventor of the machine, gives as the formula for the velocity at the circumference, for the height, H, in feet, per minute,

$$\mathrm{V}=550+550\sqrt{\mathrm{H}},$$

or in feet per second,

$$\mathrm{V}=9\tfrac{1}{6}+9\tfrac{1}{6}\sqrt{\mathrm{H}}.$$

We can compare this with the requisitions of theory by finding the value of H,

$$\mathrm{H}=\frac{\overline{\mathrm{V}-9\frac{1}{6}}^2}{9\frac{1}{6}^2}$$

and putting this equal to the value of h, as given above, we shall then have

$$\mathrm{V}=9\tfrac{1}{6}+\sqrt{\frac{\overline{9\frac{1}{6}}^2}{2g}}\times v=9\tfrac{1}{6}+1.143v.$$

It would thus appear that the practical velocity exceeds the theoretic about one-seventh, increased by a constant slightly exceeding nine feet; but this inference does not accord with the fact that the actual performance of Mr. Appold's own pump, as tested at the *Conservatoire des Arts et Métiers*, gave, on an average, hardly more than one-half the theoretic result, and was more deficient as the velocity was increased.

There is another mode of regarding the centrifugal theory which would

lead to a somewhat different expression for the power of the machine. The water entering at the central opening and passing out at the circumference, may be considered as acted upon throughout its movement in the radial direction by a continuously acting but increasing force, which, if v' stand for the *angular* velocity and r for the variable radius, may be expressed by rv'^2.

And by substituting for v' its value deduced from the velocity v in the circle in feet as itself derived from the number of revolutions per minute and the length of the radius, we shall have, for the value of the accelerating force—

$$f=\frac{\pi^2 n^2 r}{900}.$$

And if we take V to express the radial velocity generated while a given particle of water is passing from the point of entrance (say at the distance r'' from the axis) to the distance r', or the extremity of the pallet, we obtain by the ordinary process in such cases

$$V^2=\frac{\pi^2 n^2}{900}(r'^2-r''^2).$$

This velocity is imparted to a mass m, which has passed from r'' to r'; and

$$\text{the work performed}=mV^2=\frac{m\pi^2 n^2 r^2}{900}(r'^2-r''^2).$$

Or if w stand for the weight of the mass,

$$m=\frac{w}{2g};\ \text{and}\ mV^2=\frac{w\pi^2 n^2 r^2}{1800g}(r'^2-r''^2);\ \text{and}\ \frac{\pi^2 n^2}{1800g}(r'^2-r''^2)$$

expresses the height to which the mass may be raised. As every other mass passing through the pump is acted on in like manner, all the water which passes will be carried to the same height; but when the force of gravity on the column raised is sufficient to balance the accelerating force, the movement will be arrested.

This expression differs from the former in containing $(r'^2-r''^2)$ in place of r^2 simply. The two would become identical if the water were supposed to enter the pump precisely in the centre of rotation.

If the theory which ascribes the ascent of the column wholly to centrifugal force were correct, it would follow that the form of the pallets which most effectually impresses upon the fluid in the pump a rotary motion, would produce the best result; and hence that the construction originally employed, in which the pallets were without curvature and were placed in the direction of the radii, would be preferable to any other; but in point of fact this construction of the machine was found experimentally to be inferior to that subsequently adopted, and which is illustrated in the pumps of Messrs. Gwynne, Figs. 43–46, and of Neut & Dumont, Figs. 47, 48, in the ratio of two or three to one. It will be seen, indeed, by reference to the first of these figures, that the water in the annular space, G, cannot have a rotary motion in the upper part of

the ring, in consequence of the interposition of the partition at the point G. The mechanical action which does really take place is one of compression exerted by the inclined surfaces of the pallets, by which the water is forced into this space laterally, so that the circular column, abutting against the partition, is compelled to find exit in the direction L. This effect is independent of any rotary motion of the water, and indeed could not occur at all were the water to be animated by the same angular motion as the pallets. It is true that, in so far as the liquid is really thrown into rotation, centrifugal force comes into play and contributes its part to the result; but it is evident that the compressing action is the most advantageous, so that the pump in which the motion of the water is to the greatest extent radial, and least circular, will perform best. The case is analogous to that of a turbine receiving water at the centre, in which the greatest efficiency will be realized when the water leaves the wheel most nearly in the direction of the radii.

If we suppose that by the direct action of the pallets in impressing a radial velocity upon the water in the pump, and by the indirect effect of the rotary motion combined, a given elementary mass is forced from the centre to the circumference during a certain fraction of the revolution, as, for instance, one-eighth, we shall be able to compute the velocity with which the liquid would issue from a tube placed tangentially as L, and having the same cross-section as G; this section being supposed to be equal to the total cylindrical area of discharge from the rotating drum. Let the pallets measure nine inches from the point of admission of the water to the circumference of discharge, in the direction of the radius, and let the number of revolutions per minute be 900, we shall then have

$$v = 900 \times \tfrac{3}{4} \times 8 \times \tfrac{1}{60} = 90 \text{ feet},$$

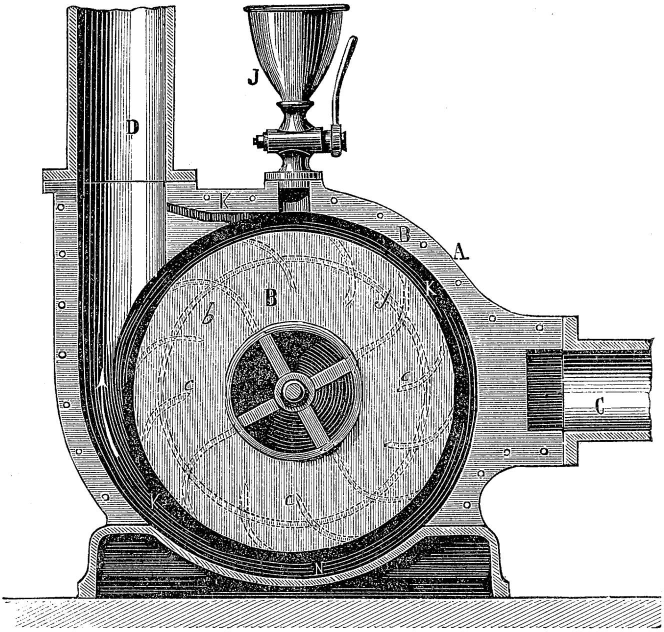
which is very nearly the velocity found theoretically by the former method of computation.

NEUT & DUMONT'S CENTRIFUGAL PUMP.

The pump of Messrs. Neut & Dumont, Figs. 47, 48, differs from that of Mr. Gwynne in the details of its construction. The pallets are more regularly curved, and are twelve in number, four only extending to the centre. The supply is admitted through a horizontal tube which conducts to both surfaces, as seen in the horizontal section, Fig. 48. The rotating drum is reduced to smaller dimensions at the circumference of discharge. This machine is also furnished with an ingenious contrivance, not shown in the figure, for preventing the entrance of air into the interior through the stuffing boxes of the driving shaft. These stuffing boxes are double, or are divided into two compartments on the axis, between which there is a water-tight annulus which communicates by a tube with the rising column of water. If, in consequence of imperfect packing or any irregularity of movement, air should be drawn in through the joints of the outer stuffing box, it makes its escape upward through this communicating tube; and if the joint of the interior stuffing box should work

loose, the only consequence which would follow would be the introduction of a small quantity of water into the pump, but no air.

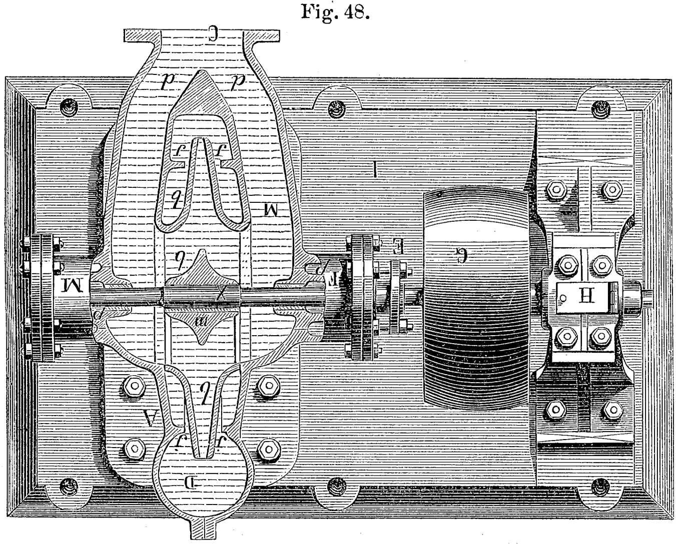
Fig. 47.



Neut & Dumont's Centrifugal Pump—vertical section.

The tunnel seen in the vertical section, surmounting the pump, is designed to fill it with water before the commencement of motion. There

Fig. 48.



Neut & Dumont's Centrifugal Pump—horizontal section.

is, of course, presumed to be a valve at the bottom of the tube of aspiration, opening upward.

COIGNARD & CO.'S CENTRIFUGAL PUMP.

In the pump of Messrs. Coignard & Co., of Paris, there is a much larger departure from the original model. A vertical section across the axis of one of these pumps is shown in Fig. 49, and another section, also vertical, through the axis, in Fig. 50. Here, there are two revolving drums G A G, both attached to the same axis D. They revolve, as before, in water-tight boxes, but the entrance of the water takes place from the space O I, between the drums; the openings for admission being at F. The discharge takes place through an annular lateral space *e e e e*, into an annular cavity M M, which conducts it to the rising tube N. The tube

Fig. 49.

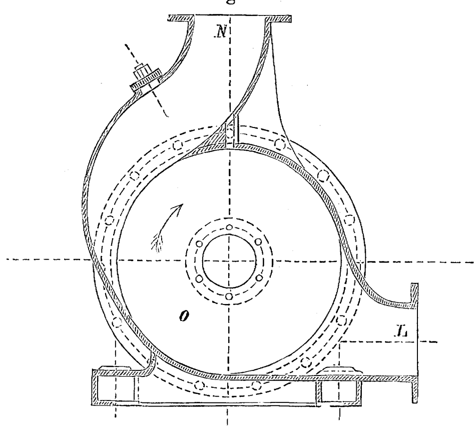
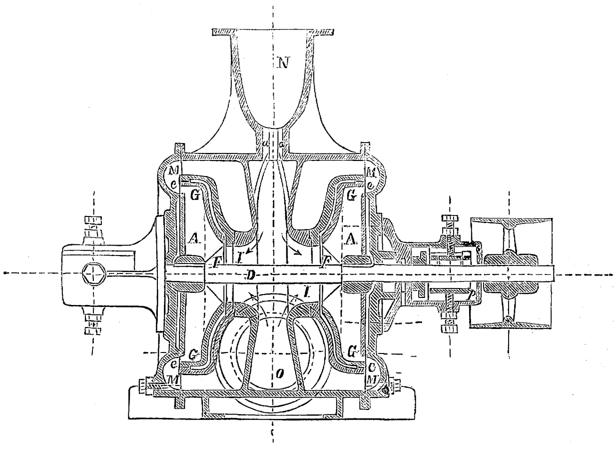


Fig. 50.



Coignard & Co.'s Pump—section.

of aspiration is L, which communicates with the space between the drums O I. The form given to the pallets in this machine is spiral; they are only two in number in each drum. As in the other pumps, the form of the helices is professedly such as to make the section of passage inversely proportional to the velocity of the water at different distances from the centre.

The obvious advantages of Mr. Coignard's construction are, the prevention of the loss of living force in the column of aspiration which occurs in other pumps by the encounter of two currents entering from

opposite sides, and the freedom from liability to receive air mingled with water in aspiration, since such air rises to the middle of the space between the drums, above the openings F F, where provision is made for its escape. It has, moreover, stuffing-boxes only on one side. The term *helicoidal*, applied to this pump by the inventor, describes the form of the pallets, and indicates that he recognizes the action of the machine to be one of compression as well as of projection. We find no record of any experimental trials of the pumps of Mr. Coignard; but it is stated that the proportion of useful work done by them amounts to sixty-five per cent. of the force expended. In the use of the pumps of Gwynne, and of Neut & Dumont, as well as of those of Mr. Appold, (not on exhibition,) the results of experiment show this proportion to be, for the first, forty-five per cent.; for the second, fifty-seven; and for the third, about sixty. These numbers give the superiority to Mr. Coignard over all the rest. It is to be taken into account, also, that the number of turns per minute in the experiments with Mr. Appold's pump averaged eight hundred, and in Neut & Dumont's only five hundred. In the case of Gwynne's pump, the average number was six hundred and forty. It is, of course, to be desired that the number of revolutions shall be kept as low as possible consistently with the attainment of the object.

Some of the pumps exhibited by Coignard & Co. were very powerful. One of them, in operation in the park, poured out a real cataract in the form of a sheet of water twenty or thirty feet wide, fifteen feet high, and several inches deep. Another, at the island of Billancourt, raised water by aspiration from a depth of over twenty-six feet and elevated it more than fifty-two feet further, being a total height of about seventy-nine feet. Mr. Coignard claims that these effects are produced with a velocity of rotation less than that required in other centrifugal pumps.

The centrifugal pump is capable of useful applications to which no other machine for elevating water yet invented would be equal. It throws out so vast a volume of water in limited time that it may be used to drain marshes, to supply water for canals, to draw the water from coffer-dams, from dry-docks, &c., and to pump out foundered vessels. For this last purpose a pump of Coignard & Co. was employed on the occasion of the sinking of the Florida in the harbor of Havre. The vessel was raised without difficulty, when, without the aid of this powerful machine, she must have been abandoned.

The fact that the helicoidal pump of Coignard, & Co., at Billancourt, was competent to raise a column of water eigty feet, and this, as specially claimed by them, *à vitesse réduite*, furnishes increased evidence of the truth of the opinion expressed above, that the action of this machine is an effect more of a compressing than of a centrifugal force. On the centrifugal theory the maximum height to which a pump of nine inches radius (the size of that employed in the test experiments on the pump of Mr. Gwynne, at the *Conservatoire des Arts et Métiers*,) could elevate a column of water, with a velocity of five hundred turns per minute, would

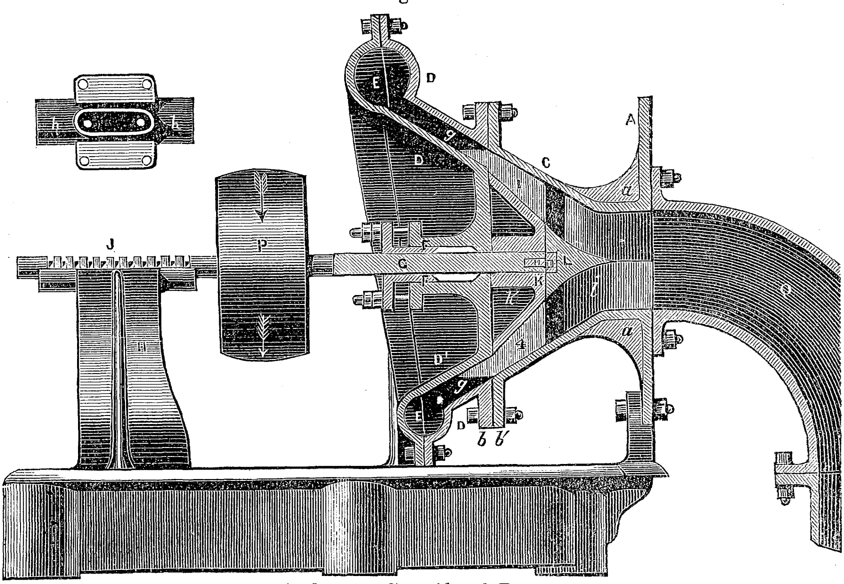
be only twenty-four feet; and by increasing the radius to one foot, the height would be increased only to forty-two and a half feet. In order that the column might rise to eighty feet, the number of revolutions would require to be increased on the first supposition to upward of nine hundred, and on the second to six hundred and eighty. These numbers by no means represent a *vitesse réduite*; and the calculations from which they are derived make no allowance for the inevitable loss of force which occurs in practice. These numbers, moreover, indicate what is required to produce a *maximum* elevation to eighty feet, at which height, of course, no water could be delivered. If the compression theory is true, the height does not depend on the rotary velocity generated in the water, but on the radial velocity, which may be greater than that which would result from the effect of rotation.

A further confirmation of this view is drawn from the fact that in certain of the pumps of the Coignard & Co., the two drums are made to act consecutively upon the same water: that is to say, the water is aspired by one of them only, and is passed from that one to the other, preserving the velocity already acquired, and receiving a new velocity in the second. This is probably the construction of the pump at Billancourt. The effect is to raise the column to a greater height than could be accomplished by using both drums simultaneously on different volumes in the ordinary way; but evidently the ultimate velocity is greater than that which is due to the centrifugal force of revolution, and the height is experimentally greater than the limit which the centrifugal theory would impose.

ANDREWS'S CENTRIFUGAL PUMP.

The centrifugal pump exhibited by Messrs. W. D. Andrews & Bro.,

Fig. 52.



Andrews's Centrifugal Pump.

of New York, is a still wider departure from the original model of Appold than that of Mr. Coignard. As shown in the annexed figure, which is reduced from the designs published in the London Engineering, in May, it has, in one view, an appearance somewhat resembling a helix, or snail's shell. This helix forms the base of a double cone placed with its axis in a horizontal position, the space between the inner and outer cones being the chamber of the pump, and being occupied by a kind of turbine wheel.

Fig. 52 is a vertical section; Fig. 53, the rotating disk, and propelling wings; Fig. 54, the stationary boss and spiral flanges. A is the base of the pump, cast in one piece with the case C, and strengthened by brackets, *a a a a*. To the chamber C is attached by flanges *b b′*, the conducting case, composed of two parts, D D′, united by flanges, *d d′*, and forming a spiral discharge passage *g* and E, commencing at *c*, and gradually enlarging to the outlet *e*. F is the stuffing box, through which passes the cast steel driving shaft G this having turned in its surface, at J, a series of grooves which are accurately fitted in a Babbitt metal box in the standard H and its cap *h*, counteracting all tendency to end-thrust or vibration. I is the bed-plate, having cast upon it the standard H, and brackets, to which the pump is secured by the flanges *d d′*, and base A. When required to be run vertically, no bed-plate is used, but the pump is secured by the base A. The base A also forms a flange, to which is bolted the bend Q with the suction pipe B attached, (shown broken off,) this pipe having a foot valve at its lower end.

Fig. 53.

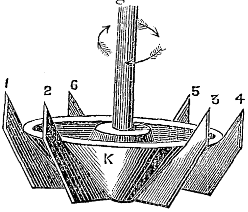
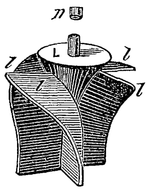


Fig. 54.



To the flange *f*, on the discharge orifice, are attached pipes for conveying the water wherever required. In Fig. 52 K is the disk secured upon shaft G, having wings, 1, 2, 3, 4, 5, 6 (see Fig. 53) upon its periphery, closely fitting the space between it and chamber C, within which they revolve without touching. Their discharge ends extend beyond K, close to the case D′, without touching it, and terminate on a line parallel to the shaft G. L is the boss connected by flanges *l l l l* (see Fig. 54,) to the chamber C, forming spiral induction passages. In the end of shaft G, is a steel button *n*, with a convex face, which revolves in contact with the convex end of the step N, secured in the boss L, supporting the shaft and disc when run vertically. Motion is communicated to the disc by a belt upon the pulley P. The pump and pipes first being filled with water, rapid motion is given to the disc K, when the centrifugal force imparted to the water between the wings causes it to flow through the passages *g* and E, to the outlet *e*; a vacuum being thereby created between the wings, which causes the water to rise through the pipe B, to keep up the supply.

By means of the spiral passages around the boss L, the water from the suction-pipe is turned gradually from a direct forward course, and delivered to the propelling wings in the line of their action; thence, through the spiral passages *g* and E it is again, by an easy, gradual curve, brought back to a straight course, upon reaching outlet *e*. The wings on the disc K, passing beyond its outer edge, create and maintain a vacuum between it and case D, and prevent sand, dirt, &c., from coming into contact with the shaft. The bearing N is in like manner protected from dirt, enabling the pump constantly to discharge a large proportion of sand, gravel, &c., without injury to any of its parts. There being no valves in action, (the foot valve remaining open while the pump is in motion, and used only to retain the charge when at rest,) and no wearing parts except the shaft in its bearings, which is perfectly protected from dirt, the friction is much reduced, enabling the pump to run for a considerable time without repairs.

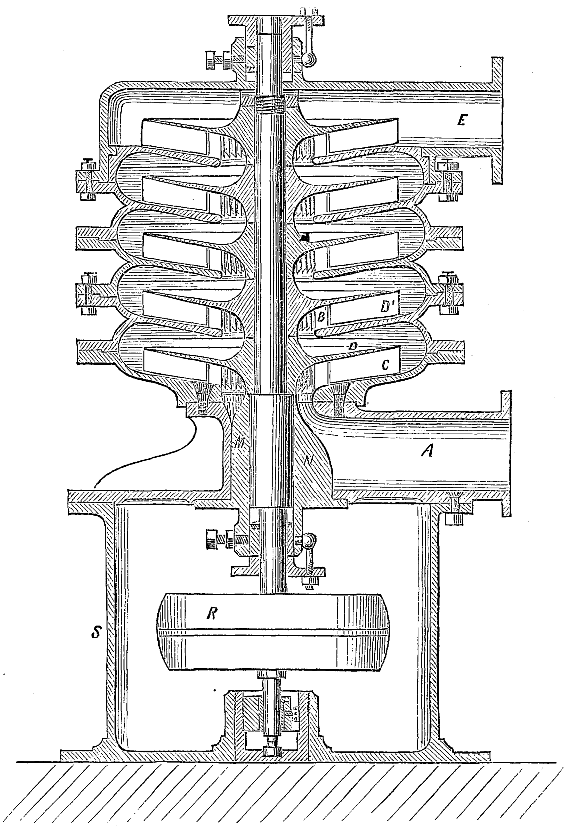
The pump, as exhibited in the Exposition, raised a large volume of water from a tank, and discharged it through a broad flat spout into the same tank again. No data were obtained by which to compare its performance with that of any of the other engines of its class; but its construction is evidently favorable in a high degree to efficiency. Of the other pumps, that of Coignard & Co., seemed to perform best; but it forces the water, at the points G, *e*, and M, (see Fig. 50) to make an abrupt turn, which cannot but diminish the useful effect, while in the pump of the Messrs. Andrews all the curves are easy, and the helix gradually enlarges up to its junction with the delivery pipe in a manner to accommodate itself most advantageously to the necessary changes of velocity. Apparently this is a very superior elevator.

GIRARD'S TURBINE ELEVATOR.

A more extended application of the principle of the centrifugal pump has been made by Mr. Girard, of Paris, in a machine called by him a turbine elevator. It is in fact something like an ordinary turbine revolving on a vertical axis, but having five distinct turbine wheels one above another on the same axis. A reference to the figure will make the construction intelligible. The water enters through the tube A, and is acted on by the pallets C, of the first turbine. Thence it returns to the centre through the space D, and enters the second turbine through E. Passing through all the turbines successively, it is finally discharged through the pipe E, which leaves the turbine horizontally, but is designed to be connected by a curve with an ascending tube. At the axis, where the water passes from level to level, it is guided by thirty-six curved plates, so fixed as to give it a direction most suited to enter the channels in the turbine wheel between the pallets. Fig. 56 shows at B the position of these guides; and the same figure shows the form of the pallets. These are twelve in number; the water as it enters taking a direction nearly radial until it approaches the circumference, when it is

exposed to the action of the inclined front of the pallet. In his first machine, the angles in these water passages were more abrupt, and the inclination of their outer faces to the circumference was less. The slight alteration increased the useful effect by one-third. It is probable that a greater alteration in the same direction would increase it still more.

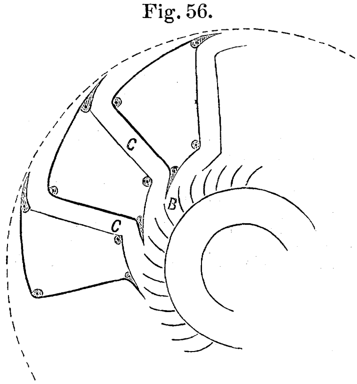
Fig. 55.



Girard's Turbine Elevator.

The idea of making centrifugal force available for the elevation of water is not a very new one; but it is only recently that a machine truly useful has been constructed on this principle. Gen. Morin, in his treatise on hydraulic machines, mentions as the earliest invention of this kind the pump of LeDemours, which consisted simply of an inclined tube firmly attached to a vertical axis, with which it revolved. The centrifugal force generated by the revolution caused the water to rise; and the tube being bent outward and downward at the top, delivered it into a circular trough. This same thing in principle was reproduced in 1855, at the exposition of that year in Paris, by Mr. Piatti, whose invention consisted of hollow and concentric cones surrounding and fixed to an axis of revolution. The water was made by the revolution of the system to rise between the cones, and was delivered in like manner at the top into a circular trough. One or two partitions dividing the conical annular space in which the water was raised, prevented the sliding of the liquid upon the solid surface, and forced it to take the gyratory motion of the containing vessel. This machine may be made a means of raising large

Fig. 56.



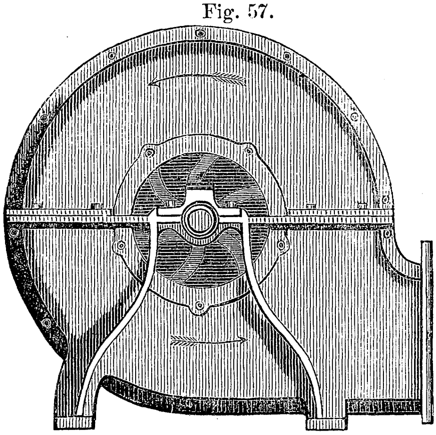
volumes of water; but the useful effect, as shown by experiments on Mr. Piatti's machine, does not exceed one-fifth of the power expended.

In 1850, or about that date, a centrifugal machine was exhibited in New York, which was claimed to be a realization of the perpetual motion. Instead of the two hollow cones of Mr. Piatti, it was proposed by the inventor of this machine to substitute a vessel in form somewhat resembling a soup plate, covered by a lid secured at the centre, but resting loosely at its circumference on the rim of the plate. From the centre of the plate beneath descended a tube, which was also the axis of revolution. This tube contained likewise a spiral like that of the Archimedean water-screw. The lower extremity was to be placed in a liquid; and the whole interior being filled with the same liquid, for which purpose a valve opening upward was placed at the bottom, the whole was to be set into rotary motion. It was presumed that the liquid, escaping by centrifugal force from the perimeter of the vessel at the top, would act by aspiration on the liquid in the column and in the vessel beneath, producing an upward current, which, acting in turn on the spiral, would exert force enough to maintain the revolution, with also a surplus outstanding to be applied to other purposes. The liquid discharged from the vessel at the top being returned immediately to that at the base of the column, provided for the permanent maintenance of the motion. Inasmuch as a liquid of so little density as water could not be expected to furnish a large amount of surplus power, it was proposed to substitute mercury; and inasmuch as mercury, under atmospheric pressure, cannot be raised by aspiration more than thirty inches, it was further proposed to enclose the whole apparatus in a strong air-tight box, and to condense the air within it to the extent of many atmospheres. Surprising as it may now seem, this extraordinary theory found many defenders, and was made the subject of a protracted discussion in the public journals, in which some gentlemen having a scientific reputation participated.

II.—BLOWING MACHINES.

LLOYD'S NOISELESS FAN.

Fig. 57.

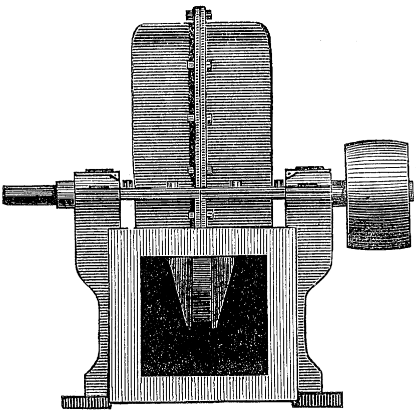


Lloyd's Noiseless Fan.

A variety of ventilators or blowing machines were present in the Exposition, of which a number were constructed substantially on the same principle as the centrifugal pumps. One of these is represented in the accompanying figures, the first of which shows only the external box enclosing the machine. The ventilator itself, which is partially seen in Fig. 58, consists of a drum formed of two flat hollow cones of thin metal, brought near together by their bases, and con-

nected by a series of curved partitions extending from the centre to the circumference. The cones are open about the vertices, and an axis of revolution supports the whole by being the common origin of all the curved partitions. This drum rotates within a closed box, and discharges the air received at the centre through a tangential outlet. The details of internal construction too closely resemble those of Appold's pump to render further explanation necessary. The figures represent the "Noiseless Fan" of Mr. George Lloyd, of London. Its recommendations are the silence with which it works and the volume of air which it delivers. Mr. Lloyd constructs a number of models varying in size from thirteen inches to four feet in diameter. The smallest are driven with the velocity of eighteen hundred or two thousand feet per minute, and the largest eight hundred or one thousand. As furnace blowers, the smallest will melt six hundred-weight of iron in one hour, and the largest one hundred and twenty hundred-weight. As an exhauster of foul air in mines, this machine is used without the surrounding box. The tube of aspiration being connected with the centre of the drum, the air drawn up is discharged from the circumference into the atmosphere.

Fig. 58.



Lloyd's Noiseless Fan.

SCHIELE'S COMPOUND BLOWING FAN.

Blowing machines of similar character were exhibited by the North Moor Foundry Co., of Oldham, England, being the inventions of Messrs. Platt and Schiele. A remarkable one among these was called the Compound Fan, designed for high-pressure blasts. In this, two fans, resembling in general the fan of Lloyd above described, were combined on the same shaft, so as to act successively on the same air. By the first the air is driven into a chamber between the fans, at a pressure of perhaps six ounces. The second receives the air at this pressure and compresses it at much more, so that it is delivered at length into the furnace at a pressure of twelve ounces per square inch. The advantages of these fans for reverberating furnaces are stated to be—

First. Great saving in fuel, the consumption being less for a given effect in proportion as the pressure of the blast is increased.

Second. Reduction of the time required for melting.

Third. A more thorough liquefaction of the metal.

Hitherto, it is stated, the highest pressure attainable by fans of any description has been only about six, or at most seven, ounces per square

inch. The improvement is, therefore, an important one. A ventilator on this same principle, constructed by Mr. Perrigault, was one of those employed in the ventilation of the palace of the Champ de Mars; whether claimed as an original French invention or not was not ascertained.

EVRARD'S ROTARY COMPRESSION BLOWER.

One or two rotary ventilators on the compression principle deserve a brief mention. Of these, one, which was exhibited by Mr. Evrard, of Mons, was a literal application to the compression of air, of the principle of the rotary steam-engine of Breval, described in another part of this report. The figure of that engine may be referred to, and will, in fact, serve perfectly to illustrate the construction of this machine. Two cylinders, whose radii are as two to one, and whose lengths are equal, revolve in contact, rolling one on the other, except where a cycloidal indent in the smaller receives a projection or pallet on the larger. In Breval's engine there are two pallets diametrically opposite to each other on the larger cylinder, and one indent in the smaller. In this machine there are four pallets attached to the larger, while the smaller has two indents. It will be easily seen that this multiplication of parts does not increase in the least the volume of air delivered, but does increase the amount of dead space, and the chances of leakage.

ROOT'S COMPRESSION ROTARY BLOWER.

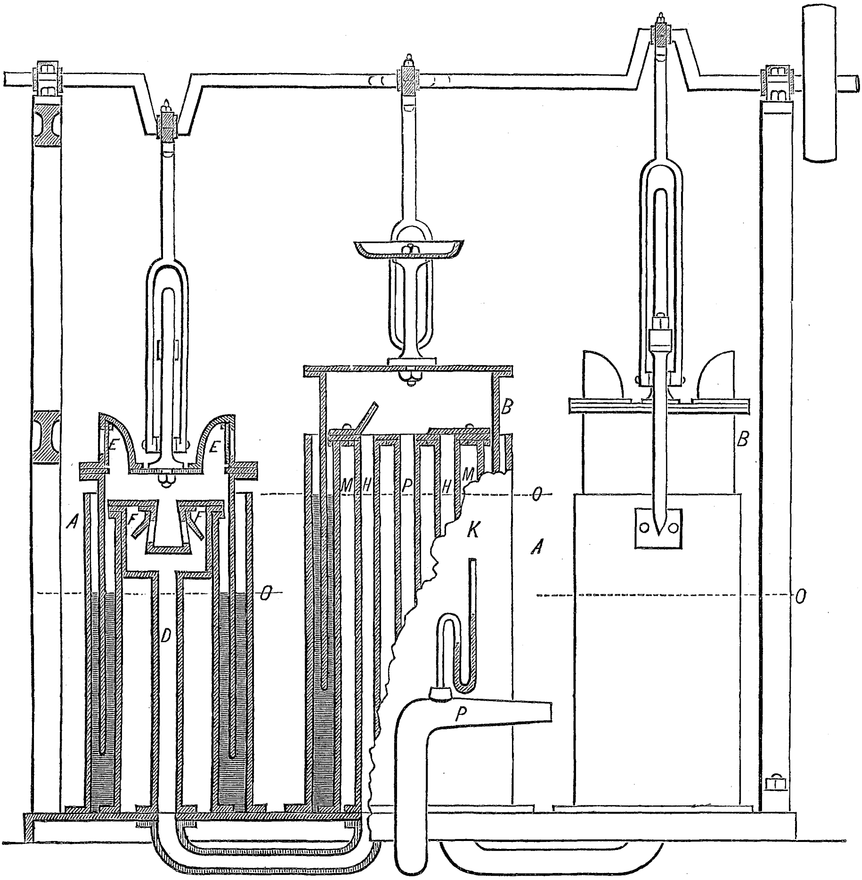
Another ventilator by compression, which was noticed with much favor, was exhibited by Mr. P. H. Roots, of Connersville, Indiana. This may be understood by supposing the rotary steam-engine of Pillner and Hills to be so modified in construction that the two toothed wheels which form the interior moving parts of that engine are replaced by two bodies having each a contour something like a lemniscate curve, or figure 8. This is substantially to replace wheels with numerous small teeth by others having each but two exceedingly large teeth. These revolve in pretty close contact, within a box to which they are fitted, so as to run as close as possible without friction. The wings being about two feet long, with a considerable length of axis, this machine is capable of delivering a large volume of air with a moderate velocity of rotation. Driven at the rate of two hundred and fifty turns per minute, it was stated to produce a pressure equal to one-third of an atmosphere, or five pounds per square inch.

THIRION'S HYDRAULIC PRESSURE BLOWER.

Still a third compression ventilator appeared in the Exposition, which, for its simplicity and its originality, seems to merit notice. It is called by the exhibitor, Mr. Thirion, of Mirecourt, France, a *machine soufflante à colonne d'eau*, but the water referred to in the name served no other

purpose but to pack the moving parts and prevent friction. The figure annexed will serve to render the construction intelligible.

Fig. 59.



Thirion's Hydraulic Pressure Blower.

Three cylinders are here seen, side by side. The two lateral ones are the compressors, and the middle one the regulator. One of the compressors is shown in section. A is a cylinder of wood or sheet metal, as may be convenient, bolted to the base which sustains the whole. Within this is another cylinder, and between the two is an annular space which may be filled to any level desired with water. The water level in the figure is shown at O. Between these two cylinders is suspended an inverted cylinder, or cylinder open downward but closed at top, which enters the annular space between the two cylinders first named, without touching either. In the top of this suspended cylinder are two valves, E and E, which open inward. A cap is placed on the central cylinder within, and in a valve-box beneath this are two other valves, F and F, which open outward as shown. From the closed space

into which these valves open, descends a pipe D, which communicates beneath the base by means of the recurved and rising tube H, with the regulator. The action of the machine will now be easily understood, it being observed that the regulator is constructed on the plan of the compressor so far as that the cylinder B, which is closed above and open below, descends into an annular space containing water, like the suspended cylinder of the compressor. The cylinder B, however, is not suspended, but is simply kept in an upright position by a guiding rod proceeding from the centre of its crown. It has also a scale pan above it to receive pressure weights, and should have a safety valve, though none is shown in the figure. The movable cylinder of the compressor is suspended from a crank or eccentric on the driving shaft of a prime mover. As in the revolution of the shaft the cylinder is lifted, air enters by the valves E, which spontaneously open. As the cylinder descends the valves E close, and the valves F are opened by the pressure of the contained air which is condensed by the force of the motor. The condensed air then finds an escape through D, and enters the regulator through H. At the top of H is a valve which is represented as raised by the entering currents. The cylinder B rises to give room for the entering air, the pressure remaining constant and being dependent on the weight with which the scale pan is loaded. The second compressor acts alternately with the first; so that a stream of air is constantly entering the reservoir from one or the other. A tube P, from the centre of the regulator, descending below the base, conducts the blast to the point where it is needed, and where it is delivered through a tuyere P. A siphon gauge attached to this tuyere shows the pressure of the air at the efflux. Of course, as the pressure is increased, the level of the water within and without the movable cylinders, both of the compressors and of the regulator, will become unequal; and the maximum pressure attainable will be only equal to the vertical height between the top of the fixed cylinder A and the bottom of the movable cylinder when at its highest point. If the water in A is in too great quantity to admit of such a pressure, it will run over until the pressure is attained. If it is in deficiency the maximum cannot be attained, but the air at some pressure inferior to the maximum will begin to escape from beneath the bell. These statements are founded on the supposition that the suspended cylinder, or bell, divides the annular space into which it enters equally. Greater pressure may be obtained by the use of a liquid heavier than water; and, for powerful blasts, Mr. Thirion proposes to employ mercury. With water he obtains a pressure of ninety-five centimetres, (about three feet,) or say a pound and a half to the square inch. Substituting mercury there might be obtained, with half the difference of level, two-thirds of an atmosphere. The pressure of a pound and a half, however, is about four times that which is furnished by a good ventilating fan, and higher than is commonly used in cupola furnaces.

This machine has four very decided recommendations. It works

almost without friction or leakage; the deterioration by wear is inappreciable; the perfect and exact regulation of the pressure is easy; and finally, the excellence of its performance depends in no degree upon precision of workmanship. It is a machine, therefore, which is especially adapted to the exigencies of furnaces in new countries and among the mountains, since it can be easily constructed on the spot, and will give no trouble in consequence of derangements.

III.—HYDRAULIC PRESSES.

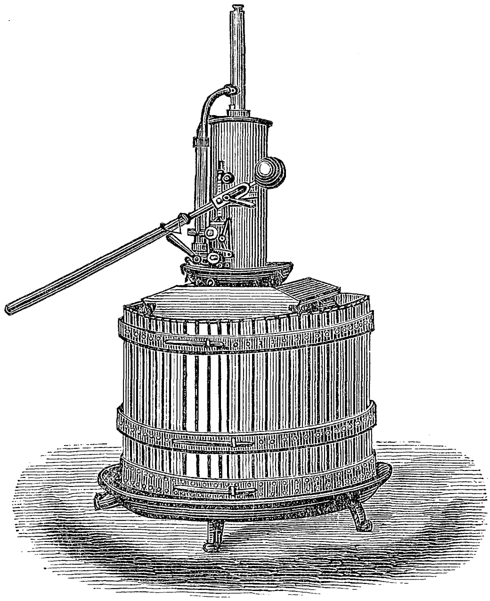
In the construction of the hydraulic presses exhibited, the ingenuity of inventors has been chiefly exercised in contriving expedients to accelerate the application of the power. One of the most obvious of these is to accumulate a large volume of water in a reservoir under a pressure equal to the maximum which it is desired that the press shall exert, and to open communication between the press and the reservoir by means of some form of stop-cock. If the pressure is to be exerted only through a small space, no other provision is necessary; but if the course of the piston is considerable, and the resistance extreme only toward the close of the movement, water may be thrown in rapidly by forcing pumps of large capacity, or introduced from a reservior under less pressure, until it becomes necessary to apply the whole power. The supply in the reservoir must be maintained by means of a steam-engine or other sufficient motor. The presses used for a time in the printing department of the United States treasury for printing the notes of the fractional currency were operated upon this principle. The same expedient has been adopted by Mr. Hessé, of Marseilles, for working hydraulic presses employed in the manufacture of oil. The form of stop-cock used by Mr. Hessé for communicating with the reservoir, and relieving the press, is noticeable for its originality and simplicity. It consists of a small hollow cylinder having three perforations which establish communication between the press and the reservoir, or permit the escape of the water from the press according as it is drawn out, more or less. The perforations are of so small dimensions as to prevent the pressure or the relief from taking place too suddenly.

CHOLLET-CHAMPION'S HYDRAULIC PRESS.

A very ingenious hydraulic press, designed to be used in the manufacture of wine, was exhibited by Mr. Chollet-Champion, of Bléré, France. In this machine it is the cylinder of the press which is movable, while the piston is fixed and forms the support. The piston, or rather the stout cylinder which forms the piston rod, stands in the middle of the bed of the press, which is constructed of strong cast iron, and rises to a sufficient height to allow for the entire movement of pressure as well as for the ultimate depth of the charge. The upper table of the press is attached to the base of the cylinder, and in order to produce the desired pressure the water is introduced below the piston. What constitutes

the peculiarity of this press is the fact that the same charge of water serves to maintain it in operation indefinitely. The cylinder is entirely filled in the beginning. If the upper table is raised to its highest point, the water will be all above the piston. It is now a reservoir of supply upon which the force-pump draws when it is operated to make the piston descend. Thus, as the movement advances, the supply of water is transferred to the lower part of the cylinder; and as the piston is fixed, the cylinder descends.

Fig. 60.



Chollet-Champion's Hydraulic Press.

The great advantage of this arrangement, apart from the incidental convenience of being independent of any outward supply of water, is found in the fact that the commencement of the movement, when the resistance is slight, takes place without any need of applying external force. A valve in the piston permits the water to pass downward freely, so long as the weight of the cylinder and the table which it carries is superior to the resistance, but this valve is closed by the pressure beneath, when the force-pump is operated.

From the description thus given it will be seen that while the descending cylinder, with the attached upper table of the press, applies a pressure proportioned to its weight, which is therefore purposely made considerable, it requires some means to be provided for raising it which shall not be laborious. The expedient by which this is accomplished is a second and small hydraulic press on the top of the movable cylinder of the larger one, to which it is firmly secured. This small press has a plunger which passes through a packing box into the large cylinder, and rests on the piston in that cylinder. When the press is at its lowest point, it is evident that both the piston of the large cylinder and the plunger of the small one will occupy the most advanced positions possible in their respective cylinders. Let now water be driven into the small cylinder by the force pump, and it will by degrees expel the plunger, which, resting on the large piston as its support, will lift the whole connected mass, including both cylinders and the upper table of the press. The length of the plunger being equal to that of the great piston, the press is thus easily lifted to the highest point. It follows, of course, that the little cylinder, having no work to do but to raise the press, is of trivial dimensions compared with the other.

One additional remark is necessary. Inasmuch as the piston rod occupies some space in the cylinder below the piston, it does not require so much water to fill the cylinder on this—that is the lower—side of the piston, as is required above; and moreover, the small cylinder requires a supply, which is discharged when the press descends. At the base of the large cylinder, and surrounding it therefore, is attached an annular basin, which serves to receive the surplus water during the descent of the piston, and to supply the deficiency when it rises. While, therefore, the main cylinder is chiefly its own reservoir, this small additional provision has to be made, but it is too trivial to occasion inconvenience.

DESGOFFE & OLLIVIER'S STERHYDRAULIC APPARATUS.

The most ingenious and most decidedly original forms of hydraulic presses and hydraulic pressure apparatus which presented themselves in the Exposition, were what were called by their inventors—Messrs. Desgoffe and Ollivier—their "*Appareils Sterhydrauliques*." If the etymology of this name does not explain the principle of the contrivance, it will be seen to be at least in harmony with it when the principle is known. The object of the apparatus, in all its several forms, is to produce a powerful hydrostatic pressure by introducing into the cylinder of a hydraulic press already filled with liquid, not an additional amount of liquid by successive impulses, as is the case in the common hydraulic press, but a solid substance, by a steady, unintermitted movement. Or, in the words of the inventors themselves, the "*Appareils Sterhydrauliques*" have for their object—

"1. To obtain a gradual pressure, without jars, by means of a liquid hermetically enclosed in a recipient which it fills, and to do this by the forcible introduction of a solid body into the recipient.

"2. To utilize this pressure by means of one or of several pistons."

The sole difference—but it is a radical difference—between the old and the new forms of hydraulic press, consists in the manner of applying the power. In the common hydraulic press, the force exerted through the piston of a small forcing pump is intermittent, and acts by fits or jolts. But in these contrivances the motive power is employed in introducing continuously a flexible cylinder or solid cord, by winding it on a pulley which is enclosed within the apparatus, while it is operated by a crank or a band wheel on the outside. The pressure produced is therefore gradually and uniformly raised; and it acts upon a piston moving water-tight in a cylinder as usual.

The construction of a press of this kind is illustrated in Fig. 5 of Plate V. P is an external pulley on which is rolled the solid cord, which is represented as at the same time partially rolled on the internal pulley P′. This internal pulley is enclosed in a strong metallic chamber which c mmunicates with the cylinder in which moves, horizontally in the present instance, the large plunger S. The driving power acts on the pulley P′, increasing the volume of the mass rolled upon it, and thus, through the confined liquid, acting upon S. By applying the power to

the pulley P, and reversing the motion, the cord may be unwound and withdrawn; thus relieving the hydraulic pressure and causing the piston S to re-enter under the ordinary pressure of the atmosphere. Although the pressure is thus applied gently and gradually, it may nevertheless be much more rapidly raised than it is usually convenient to raise it in the ordinary form of the pump. For by deriving the force applied from the motor of a manufacturing establishment, the pulley may be driven with a velocity which would probably soon derange a forcing pump of corresponding capacity. The packing of the piston, and of the axis of the pulley P′, is made of raised or upset leather, as is usual in air pumps. That of the cord is simply combed hemp. The liquid in the interior of the chamber is oil, and the material of the cord is catgut. This material is easily fashioned to a uniform diameter; it takes a high polish; it is nearly incompressible and inextensible; it is unalterable in oil; and finally, its flexibility adapts it admirably to the purpose to which it is here applied. A diameter is generally given to this cord of $0^{m}.01$, or four-tenths of an inch. As to the security of the joint formed between the cord and its hempen packing, though some apprehensions were at first entertained, they have been entirely removed by experience. The hemp itself becomes after a time so compacted as to form something like a tube of horn, exactly fitting the cord. For five months a press of this description in daily use has lost nothing by leakage, nor has it been found necessary to tighten the joint.

In the construction of this press, as the chamber for the liquid is formed of a single casting, the pulley P′ has to be introduced through the opening left for the piston. Its size being too great to allow this to be done in a single piece, it is originally formed of two equal parts, which are united on the axis.

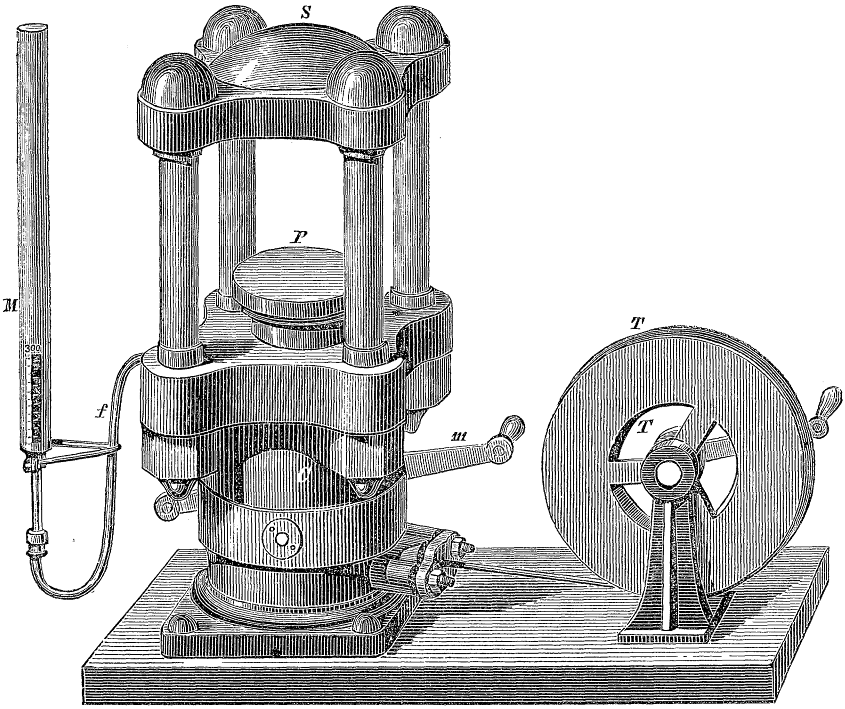
The figure to which reference has been made represents a pump which was constructed for Mr. Tresca, of the *Conservatoire des Arts et Métiers*, to be used by him in the course of his investigations on the resistance of materials of construction, and the flow of solid bodies. It received, for the convenience of these experiments, the horizontal position, and was designed to exert a force of 50,000 kilograms. In these investigations, the hydraulic press presented the only available means of applying the immense pressures necessary; but the intermittent and jerking action of the press, as operated by a forcing pump, had the effect of determining fracture of the masses compressed before the limit of their resisting power to dead pressure had been reached. The perfectly steady action of the sterhydraulic press completely remedied this imperfection, and eliminated the irregularities which had disturbed the exactness of the determinations.

The ordinary form of the press with vertical movement is shown in Fig. 6, annexed.

In this figure, a manometer appears attached to the press, to serve as an indicator of the degree of compression. This is important in experiments on the resistance of materials to crushing weights.

There is one consideration which requires attention in presses constructed on this principle, when it is necessary that the piston shall have a large movement. As the quantity of cord accumulated on the pulley increases, the resistance to the driving force increases in virtue of the

Fig. 61.



Desgoffe & Ollivier's Sterhydraulic Apparatus.

enlargement of the radius by which it acts. And this unfavorable effect occurs at that part of the course where the pressure on the piston is greatest; and where, accordingly, the mechanical advantage of the motive power ought rather to be increased than diminished. To provide for such cases, the inventors have devised the form of construction shown in Fig. 6 of Plate V, above referred to, where the pulley is smaller but the chamber is elongated, and a second pulley is introduced at the opposite extremity; the cord being in this case rolled about both the pulleys, while much the larger part of its mass occupies the interval between them.

A case may however occur, in which a very large piston may have to make so long a course, as to render it inconvenient or practically impossible to meet the exigency by the expedients thus far described; inasmuch as the quantity of cord required for the purpose might be a troublesome encumbrance. Should therefore this difficulty present itself, the sterhydraulic apparatus is constructed in the form of a continuously acting pump, and is employed to introduce liquid into the cylinder of the press, as is done in the ordinary hydraulic press; only that the entrance

of the liquid takes place still in a steady and uniform flow; and not by the spasmodic action which it is so desirable to avoid. The sterhydraulic pump is shown in Figs. 7 and 8, Pl. V, the first being a side elevation and partial section, and the second a profile and section through A B. There are now two closed chambers filled with liquid, each having a pulley within it, and the cord is transferred alternately from one to the other. The withdrawal of the cord produces an aspiration in consequence of which the valve at *i*, at the bottom of the left-hand chamber, Fig. 7, is raised, and oil enters through the tube *e* from an external reservoir, not shown. After all the cord has thus been withdrawn from this pulley, and therefore the largest quantity possible of liquid introduced into the chamber, the motion is reversed, the cord is coiled again upon the pulley, and the consequent pressure, closing the valve *i*, opens the other valve, also marked *i*, in the valve box between the cylinders. As this valve rises, it will be seen that the liquid may escape through the tube *g*, which communicates with the chamber of the hydraulic press, not represented. In order that as large a portion of the capacity of each cylinder as possible may be utilized, the pulley has arms attached to it at both ends, designed to guard the cord from slipping off, or from wedging between it and the wall of the chamber; while the diameter of the coil is increased until it occupies nearly the entire body of the pump.

It will of course be understood that the two cylinders represented are entirely alike in construction and in action. While one is drawing liquid from the reservoir by its tube *e*, the other is forcing an equal quantity into the chamber of the press by the tube *g*. At *g'* is represented a second discharge pipe, through which connection may be made with a second press, to be operated during the intervals of inaction of the first.

As it is one of the advantages claimed for this apparatus that it gets rid of valves, exception might be taken to the form of it here described, on the ground that it reintroduces those objectionable appendages. But it will be noticed that these valves open and close only once for each reversal of the movement, while during the interval a quantity of liquid passes through them nearly equal to the entire capacity of the pump cylinders. If we suppose the cord fifty metres long, say one hundred and sixty-four feet, it would force, during each alternation, five litres, or one and a third gallons, of liquid into the press. A force pump of equal diameter and of $0^{m}.1$ stroke (four inches) would have to make five hundred strokes to accomplish as much; and thus its valves would have to open and close five hundred times as often. And not only would the much greater use tend to injure in correspondingly greater proportion, but the greater abruptness with which the alternate movements would have to be made would have an influence additionally and more than equally injurious.

The constant movement of the valves in the ordinary hydraulic presses in which oil is used has the further effect, moreover, to inspissate the oil in the valve passages, and on the valve-seats; so as both to obstruct

their freedom of action, and to prevent them from accurately closing. Such consequences do not follow in the sterhydraulic pump. The infrequent opening of the valves produces little if any effect on the oil or the metal, and the long continued intermediate flow of the liquid through the openings, washes away with it any incipient resinous formation, if such occurs.

The power of the sterhydraulic press may be expressed by a simple formula, of which the correctness is obvious. If this power be denoted by W, as significant of the weight it would sustain; and if P represent the power applied externally to the lever of the driving crank, or to the radius of the driving pulley; and if R is the length of this radius or crank lever, and r that of the radius of the receiving pulley within, measured to the centre of the cord; while D and d denote the diameters of the press piston and of the cord respectively, then we have—

$$W = \frac{P R D^2}{r\, d^2}.$$

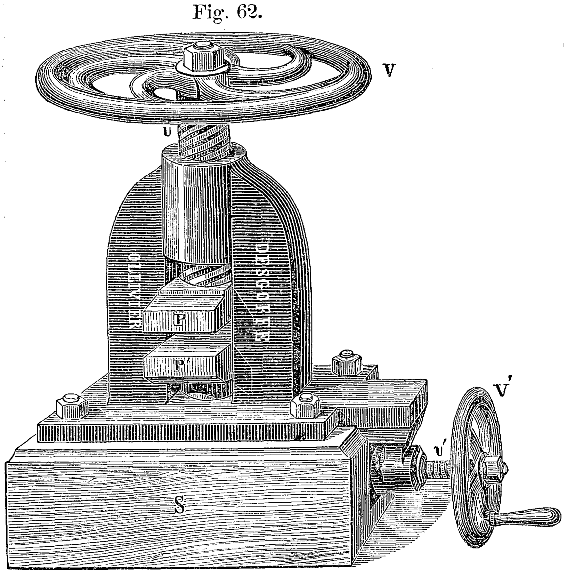
If we put P=10 kilograms=22 pounds.
R=0.25 metre=10 inches.
D=0.5 metre=20 inches.
r=0.1 metre=4 inches.
d=0.01 metre=0.4 inch,

the formula above will give

$$W = \frac{10 \times 0.25 \times 0.25}{0.1 \times 0.0001} = 125{,}000 \text{ kilograms},$$

or, say, one hundred and twenty-five tons. As the dimensions here assumed are moderate, the immense force which these presses are capable of exerting is very apparent.

Fig. 62.



Desgoffe & Ollivier's Seal Press.

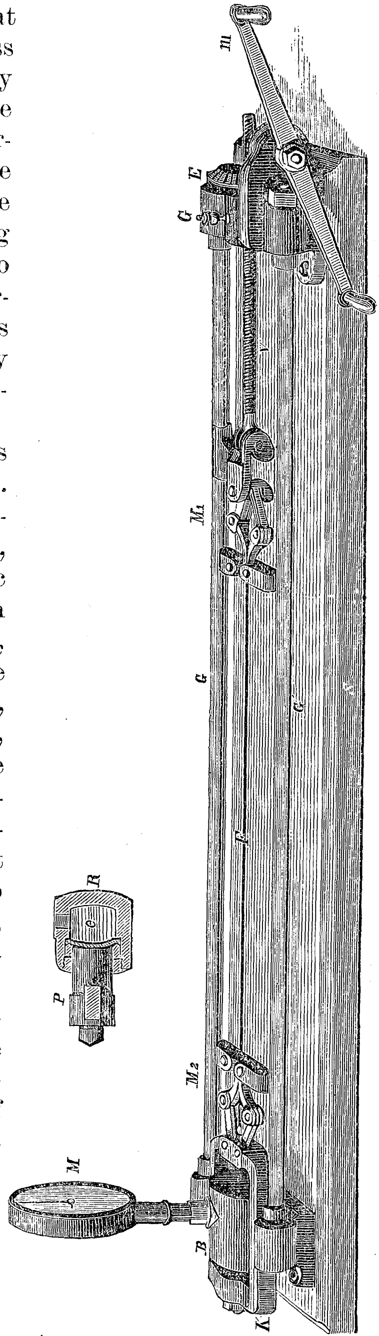
Messrs. Desgoffe and Ollivier have constructed a variety of forms of apparatus embodying the principle above explained. In the smaller forms of press, a solid rod is used instead of a cord, for the displacement of the liquid. Fig. 9, Pl. V, represents what is styled by them a laboratory press, designed to separate solids from liquids. The substance to be compressed is introduced into the cylindrical vessel I, which is perforated throughout

its lower portion, and surrounded by a jacket K. The object of the jacket is to arrest the jets of liquid expelled from the perforations, and direct them to an annular channel at the base, where they flow off through a lip at one side. The large motion in this press is given, as in a common screw-press, by running down the screw F turned by the wheel G. D is a horizontal screw entering into the chamber beneath the large piston B, which sustains the lower table of the press. While the screw F is being operated, the screw D is withdrawn to its furthest limit; but when the time arrives to apply the final pressure, D is operated by the double crank E, the body of the screw entering the cavity and forcing the piston B to rise.

Another form, somewhat similar, is shown in the wood-cut on page 202, Fig. 62. This is called a seal press, though it is employed for the purpose of forming boxes, knife-handles, and the like, out of plastic material, by compression in moulds. In this case the final pressure is greater, and the space through which it is to be exerted more limited. The large screw, marked U, has therefore a deeper thread, which is formed of several spirals. The action of this press does not differ materially from that of the last, the final pressure being given by the screw *v*; but it is much more massive in proportion to the extent of movement which it admits, and the force which it is capable of exerting is correspondingly greater.

But the purposes to which the "*appareils sterhydrauliques*" are applied are more various than would be anticipated in regarding them as simply presses. One of these is for testing the tenacity of wire under a force of longitudinal tension. In experiments of this description, it is important that the force should rise steadily, and not by intermittent jerks; both because the effect of a sudden twitch is to break the wire prematurely, and because a strain rising by steps does not

Fig. 63.



Apparatus for testing the tensile strength of wire.

furnish an exact measure of a resistance which may fall between its successive values. The sterhydraulic gauge is not liable to either of these objections. Its construction will be made intelligible by an examination of Fig. 63, annexed. In this, S represents a solid and rigid base to which the whole apparatus is secured. G G′ are cylindrical rods or columns serving to guide the slides M_1 and M_2, which carry the jaws designed to hold the wire. The construction is such as to make these jaws act automatically, closing them more firmly in proportion as the force of tension is greater. E is a bevel gear wheel acted on by another similar wheel on the axis of the double crank *m*. By turning this crank the screw V is advanced or withdrawn, so as to admit the introduction and the subsequent stretching of the wire F.

The sterhydraulic part of the apparatus is seen at R, and is represented in section in the small figure above. The cylinder R is filled with water, *e*, which is confined by a diaphragm of India-rubber. The piston P presses against this diaphragm. By means of the cross-head K, and the lateral bars shown in the cut, it is connected with the jaws which grasp the wire at M_2, and thus the entire strain upon the wire is brought to bear upon the liquid confined in R. M is a manometer to which this pressure is transmitted through the tube which serves as its support. The index of the manometer advances as the pressure rises, carrying with it a register index, which, on the rupture of the wire, marks exactly its final strain. By means of a scale and vernier on one of the columns carrying the slider M_1, the amount of stretching of the wire under determinate strains may from time to time be measured.

Another form of the apparatus is designed to test the resistance of solids to cross-strains. For resistance to crushing forces, the ordinary form of the press suffices. All these contrivances show ingenuity, and there can be no doubt that they are destined to render material services not only to industry but to mechanical science.

ASCENSEUR ÉDOUX.

The elevator of Mr. Leon Édoux, designed to lift weights by hydraulic pressure from level to level, though in its actual application employed only to elevate persons from story to story in public hotels, has naturally its place here, since in principle it in no respect differs from an ordinary hydraulic press in which the plunger has a length excessively exaggerated in comparison with its diameter. Two elevators of this description were constantly in operation during the Exposition, in the gallery of machines; and the number of visitors who took advantage of them for the purpose of ascending to the roof of the palace, and enjoying the extensive view which that commanded, amounted probably to some hundreds of thousands. The essential parts of this apparatus consisted of a cylinder twenty metres (sixty-six feet) long, sunken perpendicularly into the earth, with a plunger descending into it to the same depth, and packed water-tight at the top of the cylinder. Into this, below the packing, water,

from the source from which the Exposition received its supply for general purposes, was admitted, by means of a valve which was under the control of the attendant. The piston rose under the pressure to the required height, and was maintained there by closing the valve.

A car or kiosk, for the accommodation of passengers, rested on the upper extremity of the piston, and was elevated as it rose. The descent was effected by opening another valve which allowed the water to escape at the level of the earth's surface; when, the pressure being relieved, the car descended by its own weight. The diameter of the piston plunger was 0.25 metre, (ten inches,) and that of the cylinder only sufficiently greater to allow free water-way. The plunger was a hollow casting, turned and polished on the exterior, and closed at the bottom. It was formed of four lengths carefully united. A strong wire cable extending through the interior from end to end firmly bound the parts together, and served as a security for holding them in position in case of the occurrence of any accident.

In its ascent, the car was guided by four cast-iron columns, which formed a rectangular framework or tower around it. These columns were hollow also, affording space for the ascent and descent of heavy weights within them, by which the weight of the empty car was principally counterpoised. Chains passing over pulleys at the top connected these weights with the car at its four angles. Only sufficient preponderance was given to the car to allow it to descend without a load. The resistance to which the hydraulic pressure was opposed amounted, therefore, to little more than the weight of the varying charge.

It is to be noticed, however, that as the car ascends, the weight opposed to the pressure virtually increases, since the plunger, so long as it is immersed, is buoyed by the weight of an equal bulk of water. A compensation for this increase of resistance is provided by Mr. Édoux, in giving to the chains a weight per running foot equal to the eighth part of the thus accruing increase of weight of the piston—that is to say, about two kilogrames, or a little more than four pounds. There being four chains, and each chain being diminished one foot in length on the side of the car, and increased in length on the side of the counterpoise, one foot for each foot of elevation, the counterpoise is thus increased at the same time fifteen kilogrames, or about thirty-four pounds, which is equal to the simultaneous increase in the virtual weight of the piston.

The charge which an apparatus of this kind will elevate, the cross-section of the piston remaining the same, will depend on the height of the hydraulic head. If we assume the system of counterpoises to be such as to maintain the whole moving apparatus (supposed to be without a load) in equilibrio when the pressure of the head is shut off and the escape valve is open, or with only a slight predominance of weight in favor of descent, and to do this in every part of the course, the elevating force will be found by making the proper substitutions in the expression

$$F=\tfrac{1}{4}\,\pi\,d^2wh,$$

in which F represents the force, d the diameter of the piston, w the weight of a cubic unit (metre or foot as the case may be) of water, and h the height of the head. It was stated that the reservoir from which the supply of water was received was situated at an elevation of thirty metres above the point of application. Putting, therefore, $h=30$, $d=0.25$, and $w=1{,}000$ kilogrames, we shall obtain the result

$$F=3.14159\times 0.0625\times 30\times 1{,}000\div 4=1{,}473 \text{ kilograms nearly.}$$

Putting the average weight of an adult at sixty kilograms, say one hundred and thirty pounds, the *ascenseur* was capable of carrying up twenty-four or twenty-five persons at a time, and it usually went up full. There were in fact two *ascenseurs* working side by side; and they were constantly in motion from eight o'clock in the morning till six o'clock in the evening; making an ascent and descent at least as often as every ten minutes, or even usually in less than half that time. More than three thousand persons ascended each day, sometimes more than five thousand.

It will be seen that the ingenious system of counterpoises introduced by Mr. Édoux makes the height to which the charge is elevated quite independent of the height of the hydraulic head. Other considerations, however, practically limit the extent to which the system can be applied. In proportion as the length of the piston is increased it becomes necessary to increase its diameter and the thickness of its walls, in order that it may preserve a sufficient rigidity under the increasing strain and pressure to which it will be liable. Its weight will be correspondingly increased, entailing the necessity of equally increasing the weight of the chains and counterpoises. Thus the apparatus will become too ponderous to be advantageously employed. The weight of the pistons of the *ascenseurs* in the Exposition was two thousand one hundred kilograms, or more than two tons each. This weight exceeded, therefore, alone, not considering the cars, the whole force of elevation, by more than six hundred kilogrames; so that without the system of counterpoises the apparatus would not have worked at all.

On the other hand, for the ordinary purposes of a hotel elevator, it is not necessary to have a source of water by any means so high above the point of application as that which operated the *ascenseurs* of the Exposition. It is sufficient, we will suppose, that such an elevator may be capable of carrying up eight persons at a time, having a total weight of ten to eleven hundred pounds. Assuming an outside weight of twelve hundred, and, transforming the expression above for the value of h, we have—

$$h=\frac{4F}{\pi\, d^2 w}=\frac{4800\times 144}{3.14159\times 100\times 62.5}=35 \text{ feet nearly,}$$

putting the diameter of the piston at ten inches, and taking 62.5 pounds as the weight of a cubic foot of water.

If the diameter of the piston be enlarged to twelve inches, the hydraulic head required will be but twenty-four feet. Such an elevator can there-

fore be introduced into any house in which the water rises to a height of thirty-five feet, or even twenty-four feet, above the lowest point at which it can be conducted off after being discharged. It is desirable, of course, to have a superfluity of force, but that can abundantly be obtained in any house in which water from the public works is delivered in the third story, and communication with the public drains can be established from the basement.

Hydraulic elevators in dwellings have the advantage over mechanical contrivances for the same purpose worked by steam-engines, turbines, or other motors, because of their simplicity of construction, their extreme facility of management, their perfectly smooth and silent motion, and, in general, their large superiority in point of economy in operation. The economy, however, may not be realized in large cities, where water rates are high; but the advantages are in other respects so much in favor of these elevators, especially when the security attending their use is also taken into consideration, as to justify their introduction even in cases where it might be necessary to create the hydraulic head by means of steam-pumps. If steam power has to be used at all it may as well be employed in elevating water as in directly operating an elevator. And if this plan is once adopted the establishment becomes independent of public water-works, and even of natural sources altogether, after having provided a moderate original supply, since the same water may be constantly used over and over again. It will be necessary for this purpose to have a tank at the lowest level and another at the highest. And if we assume (as has been shown above to be just) a height of thirty-five feet to be sufficient in ordinary cases, it is not difficult to compute the work which an engine would have to perform in lifting the water required for the daily service from the lower tank to the upper.

Supposing the course of the piston to be sixty feet, and its diameter, as above, ten inches, it will require an expenditure of about thirty-three cubic feet of water for each ascension. Supposing an ascension to take place every six minutes, or ten every hour, which is about the fact at the Charing Cross Hotel, in London, and that the elevator is in operation eighteen hours a day, *i. e.*, from six in the morning until twelve at night, the total daily expenditure of water will be five thousand nine hundred and forty cubic feet—say six thousand—to raise which thirty-five feet gives a total work of 13,125,000 foot-pounds. This work a one-horse power engine would do in a little more than six hours and a half.

It would not be desirable, however, to raise the whole quantity at once, nor even desirable to have so large a quantity at a time in the tanks, since the weight of six thousand cubic feet of water would be somewhere near one hundred and ninety tons. A tank capable of containing two hundred cubic feet would suffice for six ascents; and if an engine should be employed constantly in raising the water as it is drawn down, one-third of a single horse-power would exceed the demand. Such an engine could probably be run at a much less cost than is paid in Lon-

don for the supply of the elevator of the Charing Cross Hotel, which was stated to exceed a pound a day.

HYDRAULIC COUNTERPOISE SYSTEM OF MR. ÉDOUX.

Although the invention does not fall properly under the head of machines operating by hydraulic pressure, yet the plan contrived by the originator of the elevator above described, for raising heavy masses, especially building materials, by the aid of hydraulic counterpoises, may, without impropriety, be introduced here. It is extremely simple, but where its introduction is practicable, it would seem likely to be of great utility to the builder. Two tall tripod frame-works are constructed near each other, within each of which ascends and descends a large tank made of rolled iron. Upon the top of this tank is a platform for the purpose of receiving the materials to be elevated. The tanks, with their platforms, are both attached to the same endless chain, which passes over pulleys at the tops of their respective frames. They are related to each other in the same manner as ascending and descending trains upon the inclined planes of some railroads, of which the heavier, in its descent, draws up the lighter; that is to say, their movements are in opposite directions, and when one is down the other is up. Supposing, now, the platform which is on the ground to be loaded with materials, its tank being at the same time empty, it is only necessary to lead the water of the city supply to the upper tank by means of a hose; and so soon as the weight of water thrown in this manner into the upper tank exceeds the weight of the charge on the lower platform, it will descend by its superior gravity and the load will be raised. The chain being continuous, both below and above both the two tanks, its weight will produce no effect in disturbing the preponderance, in whichever way it shall have been established. A system of clamps, or brakes, provides for the arrest of the movement at any desired point. After the removal of the load, the empty tank may in its turn be filled, the water having been discharged from the full one at the bottom by means of a valve; and thus the process can be indefinitely continued.

In order that this system of elevating heavy masses may be practicable, it is of course necessary that the water supply of the town in which it is proposed to use it should be sufficient to justify such an application; and also that the cost of the water should be less than that of the labor of men, or of the operation of machinery, which it replaces. In Paris, both these questions seem to be settled favorably to this apparatus. In New York, probably neither would be. But if it were otherwise, the adoption of this very simple contrivance would relieve very much the labor of erecting lofty buildings out of ponderous materials, and would probably very sensibly accelerate the process of construction.

GIRARD'S "PALIER GLISSANT."

The term "*palier glissant*," which does not admit of being very happily translated into an English term of equal brevity, is the name given

by the inventor, Mr. Girard, to a frictionless support, or socket, designed to sustain the axes of heavy wheels in machinery. Since it is a contrivance deriving its efficacy from hydraulic pressure, it may, without impropriety, be considered here. The friction of axles in their supports is the occasion of a considerable loss of power in every machine. The loss of power itself, though a real disadvantage, is nevertheless a matter of secondary consequence compared with the attendant elevation of temperature, which, were not means carefully provided for reducing friction to the lowest point possible, might soon be so great as to arrest the operation of the machine itself. It was stated in a public lecture delivered in May, 1867, before the Scientific Association of France, that, in a certain instance within the lecturer's knowledge, the screw shaft of a French naval propeller became absolutely welded to its support, though surrounded by the water of the sea, in consequence of the great heat developed by its revolution.

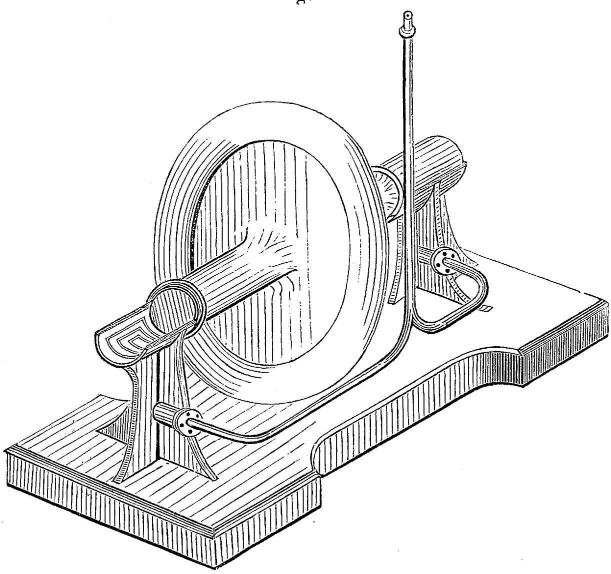
The ordinary means of reducing friction is to apply oil, or some other unctuous substance, to the parts which move upon each other. Some disadvantages attend this expedient, but till a better is suggested, they have to be endured. The cost of the oil expended in maintaining in proper condition the axles of the machinery in a foundry, or of the rolling stock of a railroad, amounts to a large sum annually; while the want of neatness which its use makes, to a certain extent, inevitable, and the labor which must be constantly employed to prevent this want of neatness from becoming much greater than it is, are serious items to be set off against its positive usefulness.

The object of Mr. Girard is to get rid of all these drawbacks by the simple expedient of substituting water for oil. It would not avail to apply water precisely as oil is applied. Though any one's experience may tell him that two smooth pieces of metal will slide more easily on each other when they are wet than when they are dry, yet every one knows also that oil facilitates the movement much more perceptibly than water; and also, that in the case of oil there is no difficulty in maintaining the lubricating film, whereas water easily evaporates, and in case of the accident of even a moderate elevation of temperature, it would be expelled from the joint entirely. Mr. Girard proposes, therefore, to employ the water to act, first, by its pressure, to lift the journal to be lubricated; and secondly, by its fluidity, to form a liquid bed or cushion between the journal and its box, on which the journal may rest in its revolution, without touching the metal of the box at all.

The construction will be understood by referring to the figure. One of the journals is represented as removed, and in the cylindrical surface of the socket are seen grooves occupying a considerable part of the area exposed. These grooves communicate, by an aperture in the middle, with a tube which is represented externally, and which sends a branch to the other journal, through which water under a heavy pressure is introduced into the box beneath the journal. The effect of the hydraulic

pressure is to lift the axle, opening a passage for the escape of the compressed water, which at the same time, because of its release from compression, loses the power to sustain the weight. If, therefore, by the first impulse, the axle is thrown upward to any sensible distance, it will immediately fall back again, once more confining more or less completely the water. After one or two oscillations, therefore, the axle will settle itself at length in a position in which, while the water will escape, it will escape but as a film of inappreciable thickness. In this condition the journal turns upon a liquid bed, and the resistance to its revolution is so excessively small that a slow rotation given by hand to a wheel sustained by it will be maintained for many minutes without perceptible retardation. In fact, the most striking illustration which can be given of the immense superiority of the *palier glissant* over a support lubricated in any other way, is furnished by placing two precisely similar wheels or disks side by side, weighing five or six pounds each, with a diameter of seven or eight inches, and journals of half an inch in diameter; one of them furnished with *paliers glissants*, and the other with boxes lubricated with fine oil. Give each of them a velocity of rotation of about one revolution in a second; the one lubricated with oil will come to rest before the other begins to give evidence of any sensible retardation; but if at any moment the stop-cock which supplies the water to the second be turned, this one will also stop, and its stopping will be instantaneous.

Fig. 64.



Girard's Palier Glissant.

It might be supposed that a journal supported in the manner above described would be unsteady and liable to injurious vibrations. This is not the case, and it is easy to see why not. When the journal is truly in the middle of the socket, that is to say when there is an equal distance between it and the wall of the socket on either side, it will be equally pressed from both sides. But if it is in the least displaced laterally, the pressure on the side toward which it moves will instantly increase, while that on the other side will correspondingly diminish; both causes con-

spiring to resist the displacement, and to maintain the journal in the position of true equilibrium. Suppose, for instance, that a weight of one ton is supported by a journal four inches in diameter, which has a bearing of ten inches in length. The horizontal section through this journal would have an area of forty inches. Of the total water pressure beneath the journal the total upward component must be equivalent to fifty pounds per square inch; but considering that this is the upward component of a uniform pressure directed perpendicularly upon a semi-cylindrical surface, the total absolute pressure must be greater in the same proportion as half the square of the diameter is greater than half the area of the circular section of the axis. That is, if P be the absolute pressure per square inch, p the mean upward pressure per square inch of horizontal section, and r the radius of the axis, then

$$P : p :: 2r^2 : \frac{\pi r^2}{2} :: 4 : \pi :: 14 : 11 \text{ nearly.}$$

Whence the absolute pressure must be sixty-four pounds per square inch. If we consider however that it is not the whole surface of the journals which is pressed upon when the water is first admitted, but only the portion opposite the grooves, which we may assume to be half the total surface, it follows that the pressure in the reservoir must be double this, or one hundred and twenty-eight pounds to the square inch, which is a little over eight atmospheres. If, now, while the axis is in the central position of equilibrium and resting on its watery cushion, a force be applied to urge it laterally, this force will be resisted by a contrary lateral pressure equal to half the weight sustained—that is to say equal to half a ton, while the counter-pressure on the opposite side will fall off on the slightest movement; so that it is apparent that the lateral stability is no less than the vertical.

The water pressure by which these "slippery supports" are supplied must be created by a force pump worked by the machine itself. The reservoir need not be large, as the expenditure of water is very minute in volume. To the objection which may naturally be made, that the working of the pump must be a tax on the motive power without return, a reply at once simple and satisfactory is found in the experience of Mr. Girard, that the working of the pump does not consume so much as half, and sometimes not more than one quarter, of the power which is lost in friction when the ordinary modes of lubrication are employed; so that by the adoption of this expedient the available power of the machine is very sensibly increased after deducting all that is expended in the performance of this additional work.

The *palier glissant* is an invention analogous to, or rather identical with, another by the same ingenious engineer, which has been already mentioned in speaking of turbine wheels, the hydraulic pivot. In that case the whole weight of the turbine and its shaft is sustained upon a cushion of water, precisely as here a similar cushion sustains the horizontal axis of a machine.

MISCELLANEOUS APPLICATIONS OF HYDRAULIC PRESSURE.

The applications of hydraulic pressure in the useful arts are becoming continually more extensive and varied. One of the most interesting of these has been made by Mr. Whitworth, who has patented an apparatus for subjecting steel to an intense pressure during the process of casting, and while it is becoming solidified in the moulds. The object which the inventor has in view is to secure sounder castings, and to render it unnecessary to use great heads of metal. The results are said to have been extremely satisfactory.

Another application of the same power in metallurgy is illustrated in the punching machines, exhibited in Class 54 of the Exposition, by Messrs. Tangye Brothers, of Birmingham, designed to punch the holes through the webs of steel rails, near their extremities, which are required in "fishing" joints. In this machine a very small movement suffices to effect the object; but very great power is necessary. Two holes are simultaneously punched, each being one inch by one and a quarter in dimensions. The pressure is applied by means of a hydraulic cylinder of fourteen inches diameter; and the water is supplied from an accumulator having a compressed air chamber, in which the pressure is raised to three hundred atmospheres. The total pressure which the press is capable of exerting amounts therefore to nearly four hundred tons. The upward stroke is effected by means of a smaller cylinder, and this smaller cylinder is always in communication with the accumulator, so that the small piston always tends to lift the ram and punches. When a down stroke is to be made, the water is admitted to the main cylinder by opening a stop-valve, this valve being combined with a discharge-valve, which is opened on the completion of the down stroke, the ram being then raised by the action of the small piston, and the water in the main cylinder flowing off through the waste-pipe. The punch holders at the bottom of the ram are so fixed to the latter that they can be readily adjusted to suit different pitches of holes.

IV.—MECHANICAL PRESSES.

For applications of pressure which require but a short range of movement combined with energetic action, the principle of the hydraulic press is, in general, most advantageous; although in some cases, as in coining, in which rapidity of action is important, this is not well adapted to the purpose, and the effect desired is produced by eccentrics, knee-joints, &c., with the aid of heavy fly-wheels. But there are many operations of industry in which large movement is necessary, accompanied by a pressure gradually increasing and becoming in the end very intense. Such, for instance, are the expression of the juice of grapes or apples, or the reduction of the volume of substances like cotton and hay into the form of portable bales. For cotton pressing, the direct action of steam is advantageously employed in our southern seaports; but steam presses

are not economically available for rural industries, and it is a problem on which much ingenuity has been expended, to construct a compressor which shall combine the advantages of original cheapness, large range of movement, simplicity of construction, and great ultimate power, without requiring any other force to operate it than is furnished by human strength. In countries in which the culture of the vine furnishes employment to a large proportion of the population, it is natural to look for numerous mechanical contrivances designed to fulfil these conditions. Many varieties of mechanical presses intended especially for the use of wine growers, but applicable with advantage to other analogous industries, were present in the Exposition, chiefly in the French department. In these the aim of the inventors, in nearly every instance, had been to produce mechanical combinations capable of being adapted, with facility and expedition, by variations in the adjustment of the mechanism, to the varying resistance required to be overcome in different parts of the course. In the ordinary simple screw-press a given velocity of the moving force produces an equally unvarying velocity of the compression platen. If the press is designed greatly to multiply the force, this velocity must be small; and in that case a press of long range will be very slow in action. When a very yielding substance is under compression, it is possible, by proper mechanical contrivances, without accelerating the movement of the power or imposing upon it a work which it cannot perform, very greatly to increase the velocity of the platen with a corresponding economy in regard to the time of the operation. In nearly all the presses exhibited, this effect is produced by systems of gearing which admit of being differently connected in the different stages of the compression, so as to vary correspondingly the velocity of the platen. In one of them, however, the knee-joint principle is employed, in which the effect of straightening the branches is necessarily to diminish the velocity of movement while increasing the intensity of the pressure. A very common mode of constructing these presses is to make the screw itself a fixed part of the construction, rising from the lower table or bed of the press, as in the hydraulic press of Mr. Chollet-Champion, above described, through the mass of the substance to be compressed. This construction necessarily assumes that it is not the substance which remains under the press after the operation is over which is to be preserved, but that which is expelled from it. Such presses are adapted to the manufacture of wine or cider, or to the expression of oil from olives, but not to cotton pressing or the reduction of merchandise of any kind into smaller compass for the sake of portability. In all the presses of this description, therefore, the force is applied to the nut, which descends along the fixed screw and drives the platen before it. In general this nut is constructed in circular form and of large diameter, and is geared on its circumference, sometimes with spur gearing, sometimes with bevel gearing, and sometimes with an internal gearing; the nut in this case being constructed with the form of a lid of a box in order to receive it.

LOTTE'S PORTABLE WINE PRESS.

A very neat press of this kind, mounted on wheels, was exhibited at the island of Billancourt by Mr. Lotte. In this press the nut is a spur-wheel of five feet in diameter, driven by a vertical pinion three feet in length, and in diameter only four inches. This pinion is then driven by another pair of gear wheels which multiply the force nine times, and finally the power is applied by means of a fly-wheel of about two feet in diameter provided with handles. The long pinion is easily thrown out of gear, whereupon the power is directly applied to the nut by means of handles at right angles to its upper horizontal surface, and the press is rapidly run down. This press, operated by a single man, gives a pressure of forty-eight tons upon a surface of about fourteen square feet, or nearly three and a half tons per square foot.

LEMONNIER AND NOUVION'S PORTABLE PRESS.

Another press, also on wheels, exposed by Messrs. Lemonnier and Nouvion at Billancourt, is very similar to that of Mr. Lotte, inverted; that is to say, the screw is attached to the platen, and passes downward through the bed of the press, the nut being applied beneath the bed. Here, moreover, instead of the long, vertical pinion, which would not be so convenient, a bevel-geared short pinion acts on the nut, which is fixed in position, and, in turning, draws the screw, and with it the platen, downward. A second gearing drives the pinion; and finally, as before, the power is applied to a fly-wheel. The movement may be accelerated by changing the system of gearing actually engaged, there being pinions of different sizes capable of being brought into action interchangeably.

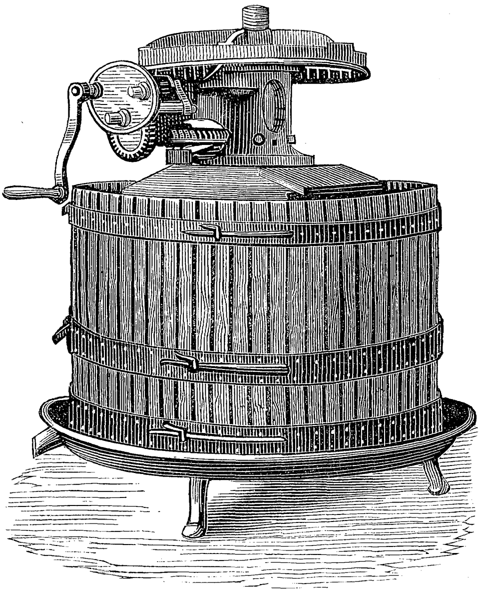
CHOLLET-CHAMPION'S MECHANICAL PRESS.

A number of presses were exhibited having two parallel screws, both operated at once by one driving power through corresponding systems of gearing. But the best of all the mechanical presses operated on this principle exhibited, was one by Mr. Chollet-Champion, whose hydraulic press has been already described. This press is represented in the accompanying Fig. 65, and the system of gearing will be made more intelligible by reference to the enlarged representation in Fig. 66. There are three arbors to which the crank can be applied, each producing a different velocity of movement in the platen. The enlarged lateral view will show that the upper two of these are the axles of pinions which can be thrown into gear with a larger wheel below them; and that the third is the axle of this larger and lower wheel itself. Upon the same arbor with this wheel is a bevel pinion which engages a large horizontal wheel correspondingly geared. The vertical arbor of this horizontal wheel carries a pinion which acts on an internal gearing in the last wheel of the series, which is the nut applying the power to the platen. The base of the construction carrying this system of

gearing is firmly secured to the platen, and the whole apparatus rises and falls with the movements of the press.

The smallest of the pinions to which the crank can be directly applied has nine teeth, and the larger one fifteen. The wheel into which these pinions gear has forty-five teeth. The bevel pinion has ten teeth, and the bevel wheel which it actuates forty-two teeth. The pinion on the vertical axis of this wheel has again ten teeth, and the internal gearing sixty-five teeth. The length of the crank is one-third of a metre, the diameter of the screw one decimetre, (four inches,) and the distance between the threads twenty-seven millimetres, (about an inch.)

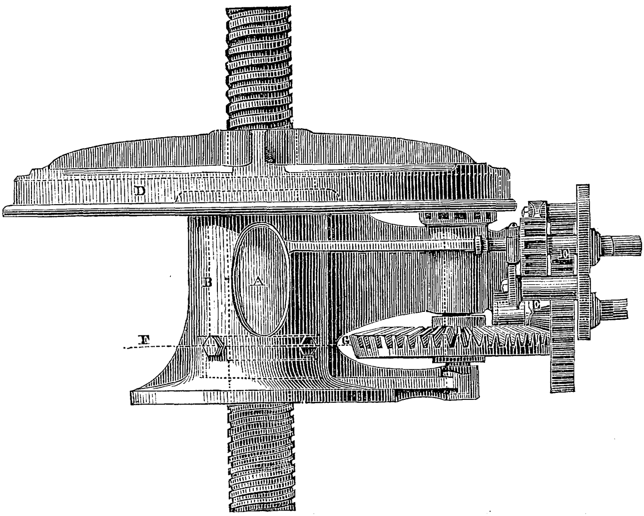
Fig. 65.



Chollet-Champion's Mechanical Press.

The force is applied successively, as follows: First, directly to the large upper wheel or screw-nut, marked D; then, by placing the crank on the axis of the vertical wheel E, which, by the

Fig. 66.



Chollet-Champion's Mechanical Press—enlarged view of upper portion.

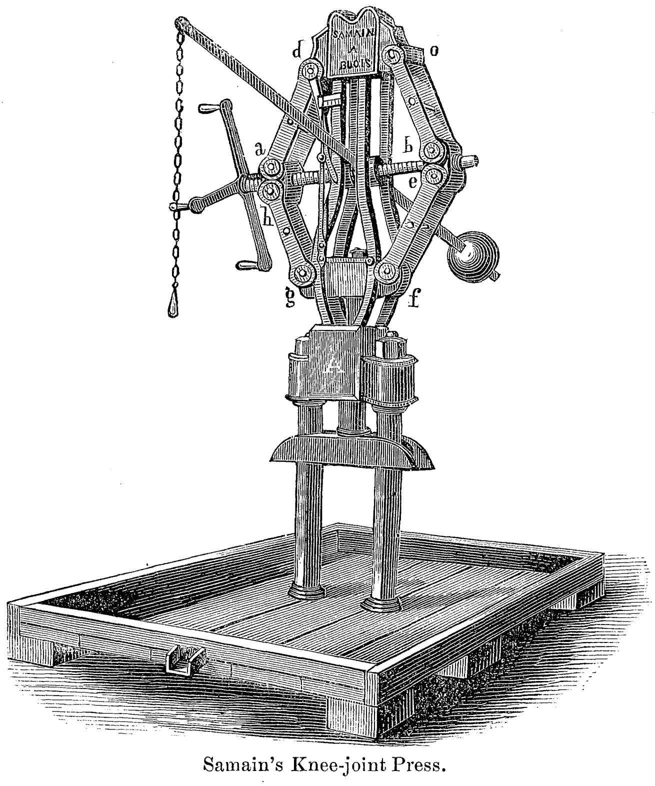
conical gearing and the gearing of the internal pinion and the wheel D, gives one turn of the nut of the press for twenty-seven turns of the

crank. When the resistance becomes too great to continue with this, the fifteen-toothed pinion is brought into gear with the wheel E, and the crank transferred to its axis. This combination gives one turn of the nut to eighty-one turns of the crank. Afterwards the fifteen-toothed pinion is thrown out of gear and the nine-toothed pinion thrown in. This gives a turn of the nut to one hundred and thirty-six and a half of the crank, and is the largest multiplication of force of which the machine admits. With this combination a man, by applying to the crank a force of fifteen kilograms, or about thirty-two pounds, can exert a pressure of nearly fifty tons on the entire surface of the body compressed. This press, for its neatness, compactness, and strength, is worthy of high commendation.

SAMAIN'S KNEE-JOINT PRESS.

One other only of these mechanical presses will be noticed, and that for its peculiarity of employing the principle of the knee-joint for high compression combined with pretty large movement. The knee-joint

Fig. 67.



Samain's Knee-joint Press.

press is recommended by several advantages. It acts spontaneously to increase the intensity of the pressure, when by the reduction of vol-

ume of the mass compressed the resistance becomes greater; and as the limit of the movement is approached, the ratio of the power to the resistance becomes mathematically unlimited. The construction is simple, and the loss of useful effect by friction is less than in the presses which act through gear-wheels. On the other hand, in a press of this description a large range of movement cannot be obtained without giving to the machine much greater dimensions than are necessary in ordinary presses of equal power. The press represented in the annexed figure was exhibited by Mr. P. Samain, of Blois, France. It is constructed of several sizes, furnishing an actual pressure of from twenty to one hundred tons. The smallest is about seven feet, and the largest about twelve feet, in height.

As the figure shows, the power is applied by means of a double knee-joint articulated at the top to the upright framework, and at the bottom to a cross-head, from which proceeds the shaft which applies the force, and which works through a guide. At the junction of the branches the articulations are made with masses of metal forming screw-nuts, through which passes a horizontal screw, right-handed for one-half its length, and left-handed for the other half. This screw is operated at first by means of a set of crank-handles at one end of it; and when the resistance becomes very great, by means of a counterpoised ratchet lever, which is shown in the middle of the frame. The force applied in this way is very great, since the operator can act on the lever with his whole weight.

The frame of this press has been constructed by the inventor so as to serve as a dynamometer, showing the amount of pressure at any time exerted. The head-piece into which the arms articulate is connected with the body A by means of iron or steel bars, having a certain curvature which the pressure tends more or less to straighten, according to its intensity. An upright needle, which is seen in place at the left-hand extremity of the cross-head, is moved, as the straightening goes on, progressively toward the right, and its upper extremity indicates the degree of pressure upon a fixed scale attached to the frame. This needle has likewise another function to perform. As, theoretically, when the branches of the knee-joint are nearly in a straight line, the force approaches infinity, there is a possibility that, in certain circumstances, the parts under strain may be fractured. In order to prevent the occurrence of an accident of this kind, an arm attached to the frame at *d* is moved by the needle toward the lever; and when the limit of safety is reached this arm interposes an obstacle to the movement, and makes it impossible for the operator to carry the pressure further.

The knee-joint press, though rarely seen in use, is not a novelty; but the model presented by Mr. Samain is conveniently arranged, and the dynamometrical feature, which is original, is a very useful addition. A press on this principle has been in use in Mobile, and perhaps in other southern seaports, for pressing cotton. In order to adapt it to a pur-

pose requiring so large a range of movement, it is necessary to construct it upon a pretty large scale. The knee-joint cotton presses of Mobile, which are worked by steam, are in height not less than twenty-five or thirty feet.

CHAPTER VII.

METERS FOR LIQUIDS AND FOR GAS—BOILER FEEDERS.

SPIRIT METER OF SIEMENS AND HALSKE—VOLUMETER AND ALCOHOMETER—DUBOYS'S WATER METER—CLEMENT'S WATER METER—PAYTON'S—COCHRANE'S METER FOR LIQUIDS FLOWING UNDER PRESSURE—GAS METERS—SUGGS'S PHOTOMETRIC GAS-MEASURING APPARATUS—CONSTANT LEVEL METER—BOILER FEEDERS—RIEDEL'S—HOUGET & TESTON'S.

I.—METERS FOR LIQUIDS.

Instruments designed to measure and record the quantity of a liquid or of a gas passing through them were present in the Exposition of 1867, as in former Expositions, in numbers. The most elaborate and certainly the most ingenious of these was one which was exhibited by Messrs. Siemens and Halske, of London, and which was designed by them as a meter for alcohol. In addition to the measurement of the volume, a function to which in general contrivances of this class are confined, it is the purpose of this apparatus to register the *quality* of the liquid; that is to say, the amount of absolute alcohol contained in the measured volume passing through it. Two sets of register dials therefore appear on its face; upon one of which may be read the total volume of the liquid which has passed, while the other shows the total amount of absolute alcohol which the whole contains.

SPIRIT METER OF SIEMENS AND HALSKE.

This instrument embraces, therefore, two distinct pieces of apparatus which may be separately described. The *volumeter* consists essentially of a hollow drum divided by a concentric cylindrical partition. In the annular cavity between the two cylindrical surfaces there are constructed three separate chambers, each capable of containing five litres. The liquid is received into the small central cylindrical space through the axis of rotation. Three slits in the cylindrical partition permit the liquid to flow successively into the chambers according as each in turn occupies the lowest position. The openings are so arranged that, while the lower chamber is filling, the level in the receiving cavity is too low to permit an escape into either of the others; and it remains stationary until the lower chamber is quite full. It then rises and the liquid begins to overflow into the chamber next following in the order of rotation, increasing the weight on that side and causing that chamber to descend. The discharge of the full chamber then commences, while the aperture through which it received its supply is carried by the rota-

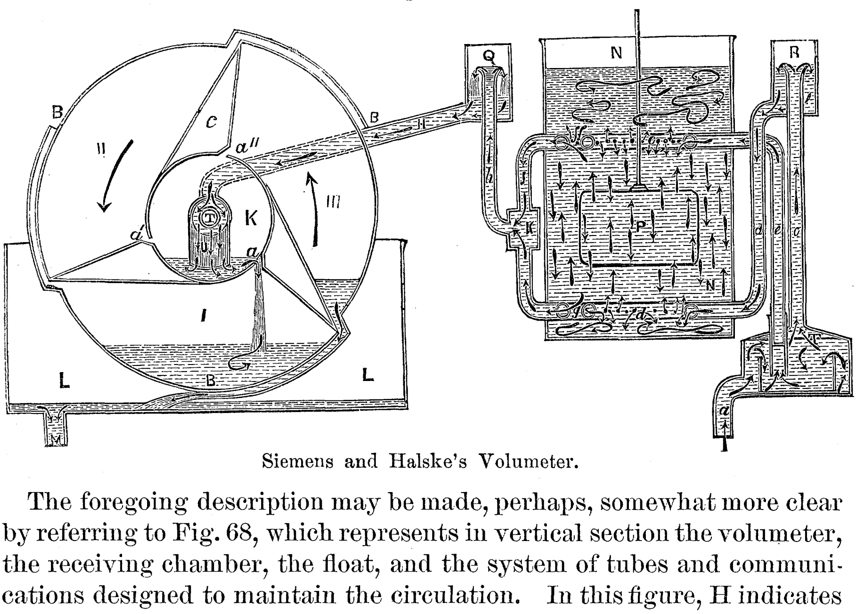
tion above the level of the liquid in the central cavity. In order that no outflow may take place until this change of position has occurred, the channels of discharge are carried spirally from each chamber round the exterior of the one next following, in form something like the curved floats of a turbine wheel. A rotation of about 60° from the stationary position is necessary before the discharge can begin. The liquid then flows into a tank which surrounds the lower portion of the drum, and is conducted off by suitable arrangements. By the rotation of the drum the registering dials are actuated in the usual manner.

The portion of the apparatus by means of which the amount of pure spirit is determined and recorded consists, in its principal feature, of a hydrometer on a large scale, floating in a vessel through which the liquid passes on its way to the volumeter. This float is constructed of thin sheet brass, and is filled entirely full with strong spirit. The air having been expelled by boiling, it is then hermetically sealed. This expedient makes the hydrometer practically independent of the fluctuating temperature of the liquid measured, inasmuch as the changes of density of the float will be sensibly the same as those of the liquid itself. The stem of the float is connected with the short arm of a lever which rises and falls with it, the apparatus being so counterpoised as to yield to the slightest effort of the float as it rises and falls with the varying density of the liquid in which it is immersed. The long arm of the lever actuated by the float terminates in a point or edge, which has a certain range of movement through an arc extending to some degrees above and below the horizontal. If a divided scale were placed behind this point, it might be so graduated as to enable an observer to read at any moment the density of the liquid in the tank. But as the object in view is not to *indicate* merely but to *record*, an additional mechanism is necessary to give motion to the registering dials. The principal of this mechanism may be understood from the following general explanation: Immediately under the point of the lever just mentioned, and at a convenient distance, is the axis of the first of the wheels of the register; on this axis moves freely an arm which is capable of an oscillating motion, by which it is brought up at regular intervals against the point of the indicating lever, meeting this lever nearly at right angles. The point arrests its motion, and the arm is curved in such a manner that this arrest takes place sooner when the point is depressed than when it is elevated. In this direction, therefore, the limit of the oscillation is variable; but in the opposite, it is constant. When the liquid in the tank which contains the hydrometer is pure water, the float is necessarily at its highest point, and the end of the indicating lever will accordingly be at its lowest. The adjustments are so made that, under these circumstances, the oscillating arm has no liberty of oscillation at all. On the other hand, if the tank is filled with absolute alcohol, the float settles to its lowest point, and the oscillations of the arm attain their maximum. It only remains to contrive that these oscillations shall occur at the exact

intervals when a determinate quantity of liquid is delivered by the volumeter; and the connection between them and the registering apparatus is afterwards only a matter of mechanical detail, which requires no originality of invention. This end is attained by connecting with the axis of rotation of the volumeter a three-leaved cam, one leaf of which passes each time that a chamber of the volumeter is emptied of its contents. This cam, by suitable connections, determines the movement of the arm; and at the same time, by means of a ratchet wheel of large diameter and fine teeth, which is fixed on the axis of the first of the register wheels, causes that wheel to turn through an arc equal to the angular movement of the arm. From what has been said it will be inferred that the curvature of the arm is such that its angular movement is proportional to the quantity of pure alcohol contained in the measured quantity of liquid at the density indicated at the moment by the position of the float.

One additional provision, rather important to the correctness of the indications of the hydrometer, has been attended to, which remains to be explained. A mixture of alcohol and water standing in a vessel at rest is liable to settle in strata of unequal density. It is indispensable to prevent such a condition of things from establishing itself in the tank which contains the float. The inventors have, therefore, provided a system of tubes for introducing the liquid into the tank and for withdrawing it, by means of which contrary upward and downward currents are propagated incessantly throughout the mass. The continual intermingling of all the strata thus serves to maintain a density perfectly uniform.

Fig. 68.



Siemens and Halske's Volumeter.

The foregoing description may be made, perhaps, somewhat more clear by referring to Fig. 68, which represents in vertical section the volumeter, the receiving chamber, the float, and the system of tubes and communications designed to maintain the circulation. In this figure, H indicates the tube by which the liquid is introduced into the central chamber of

the volumeter. So soon as the level in this chamber reaches *a* the liquid overflows into the cavity I; and until this cavity is filled the level is stationary. But when escape by this passage ceases to be possible, the level rises, and an overflow commences at *a'* into the cavity II on the left.

The equilibrium of the vessel being thus disturbed, a rotation commences, and the chamber II descends. The point of efflux B, corresponding to the chamber I, being in this movement brought below the level of *a*, discharge commences from I, and continues until that chamber is emptied and the chamber II reaches the lowest place. The operation thus proceeds continuously.

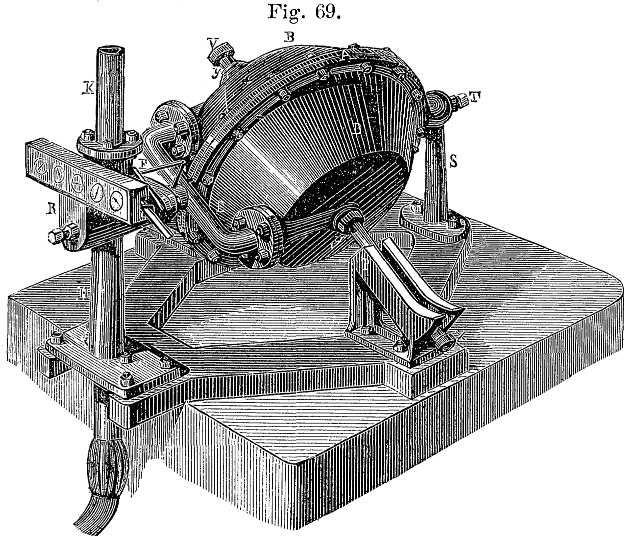
The system of circulation will be better understood by a mere inspection of the portion of the figure on the right representing the receiving vessel, with the float P, and the system of distributing tubes, than by any description. The liquid introduced at G into the closed vessel T is divided into two portions, one of which ascends through *c*, overflows at R, and descends through *d* before entering the tank, while the other rises through *e* and enters at a higher point. Opposite currents are thus delivered both above and below the float, and the density is maintained uniform throughout the vessel.

It must be said of this apparatus, as of nearly every thing which originates with Mr. Siemens, that it is characterized by singular ingenuity. As a volumeter it seems to be perfect. Whether the sensitiveness and accuracy of the alcohometrical parts of it will prove to be equally satisfactory can only be determined experimentally.

WATER METER OF MR. E. DUBOYS.

Mr. E. Duboys, of Paris, exhibits a form of water meter which, for its simplicity and the necessary accuracy of its measurements, must be well adapted to those cases in which great rapidity of flow is not important. It is also especially suited to the measurement of water under pressure. The construction can hardly be well explained without a figure. The wood cut annexed, Fig. 69, presents an exterior view of this meter; and the interior is shown in

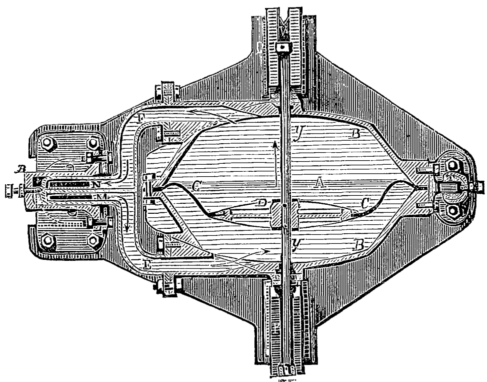
Fig. 69.



Duboys's Water Meter—exterior.

section in Fig. 70. The contrivance consists of two basin-shaped vessels applied to each other so as to enclose between them a cavity, which is divided by a flexible diaphragm of India-rubber. To the central part of this diaphragm is fixed a weight D with a double metallic disk, including between its parts the sheet of rubber, and adapted in form to the central bases of the cavity. This weight and its disk are kept in position by a rod y which passes through the bases, and serves to guide the movement of the diaphragm. At M and N are the apertures for the reception and discharge of the water. It is seen, by the direction of the arrows in Fig. 70, that if water enters through the duct ME it will press upon the under surface of the diaphragm and disk, gradually filling the entire vessel, the water above the diaphragm meanwhile escaping through FN, so that finally the flexible diaphragm will apply itself closely against the upper surface of the vessel.

Fig. 70.



Duboys's Water Meter—interior.

During this process the position of the apparatus is inclined, as shown in Fig. 69; and when it is complete the weight D will be on the upper side and will cause that side to preponderate. The vessel being suspended on pivots will now tilt over, and by this movement will cut off the supply from the full side, at the same time opening the discharge valve for the escape of the water which it contains; while on the other side, at the same moment, the contrary effect will be produced. Another charge will consequently now be admitted into the vessel, when the apparatus will tilt once more.

It is evident that the preponderance of the upper side of the vessel will occur before the entire completion of the filling; but were the position to be then immediately changed, the accuracy of the instrument as a meter could not be depended on. Provision is made against this in the following manner: P and Q are two troughs or grooves, undercut, so that the section presents the form of a bracket. At the extremities of the rod y are seen two square heads. These heads are too large to enter the groove except at its ends; but the diameter of the rod is small enough to permit it to pass through in its whole length. When the apparatus tilts it is because the head, which is then lowest, falls beyond the extremity of the groove; but as the rod enters the groove at one end and moves longitudinally, the head must traverse the whole length of the groove before it can escape. Although, therefore, the upper side of the vessel becomes the heaviest some time before the filling is com-

plete, the head, which is held by the bracket, prevents any movement until the disk D comes fully into contact with the base of the cavity. This meter was in constant operation during the Exposition, and its performance appeared to be perfectly regular.

CLEMENT'S WATER METER.

Another form of meter exhibited by Mr. J. A. Clement, of Orleans, while more complicated than the last, and quite different in mechanical construction, presents a certain resemblance to that in the adoption of flexible membranes as the essential organs of its moving parts. Externally this meter exhibits the appearance of an upright cylinder, into which water is conducted at the base on one side, while the discharge takes place from the centre. Five chambers are placed symmetrically in the interior, into which the water is successively admitted. On the sides of these chambers toward the centre they are closed by flexible membranes of India-rubber, each being strengthened by a metallic plate, to which is attached a connecting rod designed to actuate a crank on a vertical axis in the centre. Thus there are five cranks all operating the same axis, but set at equal angles from each other in the horizontal projection. The central axis carries a compound or many-way stop-cock, which, as it turns under the pressure of the water, opens communication between each chamber and the water of supply, and also with the channel of discharge, successively. There being five in all, three are constantly discharging while the remaining two are filling.

This meter operates fairly, the error of measurement being within the limit of one or two per cent. It was claimed for it that it is not liable to clog, in case the water carries solid matter in suspension; a statement which, within certain limits, may be true; but the discharge through a cock must impose the condition that there shall be nothing carried along in the nature of vegetable *debris*, which would be very likely to be jammed in the discharge orifices when closing.

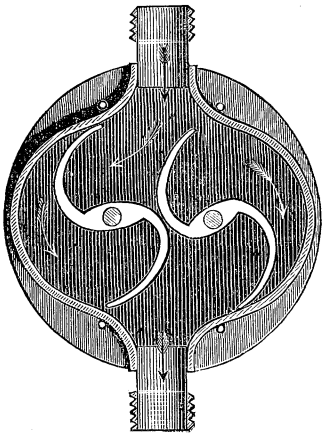
PAYTON'S METER FOR LIQUIDS.

A meter was exhibited by the London Water-Meter Company, which they claim to be capable of delivering a larger quantity of water in a given time, in proportion to its size, than any other meter yet invented; and which they also guarantee to work equally well under all pressures. This meter somewhat suggests, in its construction, the rotary engines of Behrens, and of Pillnner & Hill, as it embraces within the same box two rotary parts which inosculate with each other. This resemblance will be recognized by inspecting the accompanying figure. 71

But it differs from the machines just named, in the respect that the mass of the rotary parts is comparatively small; so that they displace but an insignificant amount of liquid compared with the total volume passing through. These rotary parts are shaped very much like the letter S, the arms of the letter having a cycloidal curvature such that,

in the revolution, the end of one runs in contact with the hollow of the other. This is what happens periodically in the Behrens engine, as heretofore described. The ends of the two letter S rotaries which are not engaged with each other, are at the same time in contact with the outer wall of the enclosing box. It follows, from these statements, that there are extended junctures made by simple contact, on the tightness of which depends the prevention of the percolation of water through the instrument without being measured. And these joints cannot be packed without creating a friction which will be equally prejudicial to their satisfactory performance. The whole of the lateral surfaces of the rotary apparatus must move freely over the plane surfaces of the ends of the box; and the edges of the extremities of the cycloids must move in the same manner over the whole cylindrical surface. Notwithstanding this apparent liability to leakage, the instrument is asserted to perform without change of rate under all pressures.

Fig. 71.



Payton's Meter for Liquids.

COCHRANE'S WATER METER.

In the United States section was exhibited a water meter for measuring liquids flowing under pressure, which, from an error of classification, failed to come under the notice of the proper jury. Objects of this description were assigned in the programme of the imperial commissioners to Class 53. Cochrane's meter was entered in Class 12, where it was out of place, and was passed without attention. As it embraces all the important elements of a good meter, an attempt will be made to describe it here. The general appearance of the apparatus is shown in the figure, and is that of a cylindrical or cylindro-conical vessel, glazed for about one-half its altitude from the top, and constructed of metal below. The measurement is made by means of a vessel having somewhat the form of a double scoop; this being divided in the middle by a partition, and balanced upon a pair of pivots in such a manner as to tilt alternately from the one side to the other, when by the flow of the water into the more elevated chamber the equilibrium is disturbed. Other inventors have employed this mode of measurement for liquids before; but as it requires that the measuring vessel shall not be immersed, it has not before been successfully applied to the case of water under pressure. Subjoined is the inventor's description, which is sufficiently explicit to require no addition.

"Fig. 72 is a perspective view of the whole, the upper portion being of glass, to allow a view of the interior. The small sections show, on a

larger scale, the device for supplying air. Fig. 73 is a vertical section of the whole, as ordinarily constructed of cast-iron.

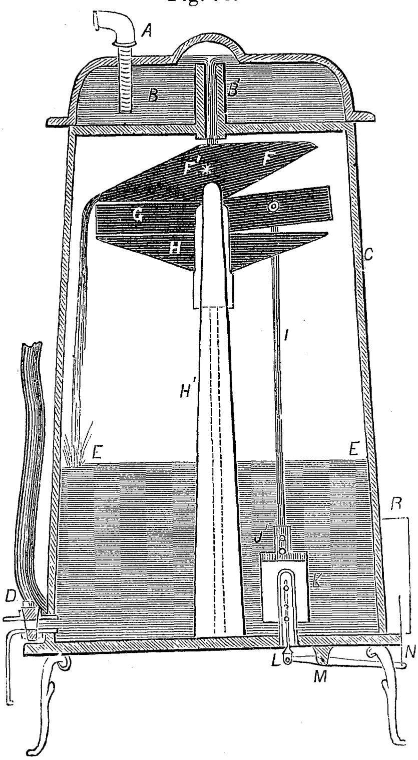
Fig. 72.

Cochrane's Water Meter.

"A is the pipe which supplies the water, and B a receiving and retarding vessel bolted upon the top of the main case C. This vessel serves as a kind of air chamber, and allows the water to fall gently into the cup below. D is a cock, through which the water is discharged, and E E is the surface of the water within; it being understood that the air above E is at the density required to equal the pressure due to the head of water.

This density is acquired in the first instance, simply by the rise of the surface E E, which thus compresses it. F is the rocking cup, and F′ the partition therein. The cup being supported on suitable bearings, its pivot is free to roll horizontally, to a slight extent, and thus to make the resistance a rolling rather than a sliding friction. G is a lever, mounted in the same frame with F, and immediately below it. It is slightly bent, as described, and immediately below it is a cross bar H, which regulates the extent to which either end of the lever G may, be depressed.

Fig. 73.



Cochrane's Water Meter—section.

"The centre of gravity is thus lower at either extremity of its motion than at the middle of its vibration; and, in short, by well-known laws, the cup inclines with a certain uniform degree of force, to remain at either extreme of its motion. The water received from B through the tube represented, accumulates on one side of F′ until its gravity is sufficient to overcome this tendency, when the cup rapidly tilts, and discharging its load on that side commences to receive an equal amount on the other. There is no resistance to the commencement of this rocking motion, except the gravity of the cup F and the rolling friction of the support, but towards the close of its motion it strikes the elevated end of the lever G, and depresses it. The devices for recording the strokes, and also for receiving the air, are worked from this lever G, by the aid of the rod I; and both these operations, though necessarily communicating with the exterior of the case, are performed without the aid of a stuffing-box of any kind.

"The tight joint required at the point where the motion is carried out through the case is obtained by the use of a kind of miniature slide valve, held to its seat by the pressure of the fluid within. A hollow projection K extends upwards from the bottom into the interior of the case, A. Its interior communicates freely with the atmosphere, and its exterior is plane on one side and perforated as represented in Fig. 72, the perforations being covered by the small slide valve J. This slide valve is connected by the rod I to the lever G, and consequently moves vertically on the plane surface of K, at each movement of the latter.

"The indicating mechanism is on the exterior of the case. It is similar to that ordinarily employed on gas meters and the like, and carries

several indexes, which work on the face of corresponding dials, as represented by R, in Fig. 72. A ratchet wheel on the lowest and quickest shaft is operated by a pawl, which latter is connected to the work inside through the rod, L, which stands loosely enclosed in the interior of K, and is connected firmly to the slide valve J at the point K′, Fig. 72. This connection avoids the necessity for a stuffing-box.

"When the valve J is in its lowest position, the water in its interior escapes through the aperture K‴ and air from the interior of K flows in through the aperture J to supply its place. Now, when, by the means described, the valve J is raised to its highest position (that represented in the figures) the air freely escapes from the interior of J through the cavity J′, and water finds access through side openings, imperfectly represented by dots, so as to flow in through J″. At each movement of G, therefore, the indicating apparatus R shows that water has been discharged from the cup F, and also allows a quantity of air to rise in bubbles through the water.

"The various pipes and cocks connected to the base of the case C serve to draw water therefrom in the usual manner. They may discharge it directly at the cock from which it is seen flowing, or may lead it in the pipe represented to any distance, and the whole apparatus serves as an air chamber to regulate the motion of the water.

"The device for receiving air is made a little larger than necessary, in order to insure a sufficient supply of that fluid within the case. Under ordinary circumstances, no harm can arise from a too great accumulation of air, as the aperture K″, which obstructs the water, being higher than either of the other outlets, it simply follows that if the water surface becomes too low, small quantities of air instead of water are discharged through the cavity of the slide valve J, and as the density of the air escaping is greater than that introduced, the effect of this device is to reduce rather than increase the quantum of air in the case C; thus there is no possibility of too much air accumulating, except under unusual circumstances. In case the pressure in the street main should be suddenly diminished, in consequence of the bursting of a pipe, or of an extraordinary quantity being drawn out in case of a fire in the vicinity, the air enclosed in C, by expanding, might force its way backward into the main. To avoid this, the reservoir B is arranged, as represented, so that it will receive and contain any air which might thus be displaced, and hold it ready for discharge into the case C again, so soon as the pressure is restored."

II.—GAS METERS.

The devices for measuring gas presented in the Exposition were almost innumerable. There were very few, however, present which had not appeared in previous international expositions. Out of the great number, one or two seem to possess sufficient interest to deserve a cursory mention. One of these is the photometric gas meter of Mr. William

Suggs, of London; and another the constant level gas meter of the London Gas Meter Company.

SUGGS'S PHOTOMETRIC GAS MEASURING APPARATUS.

The object of this apparatus is to show not only the volume of gas which has been consumed at the end of a given time, but also the rate per hour or per minute at which the consumption is proceeding. This rate it is, of course, necessary to know when testing the quality of gas in regard to its power of illumination. Assuming as a unit a given light of constant intensity, the value of the gas light will be determined by comparing the brilliancy of its flame as produced in a burner of standard form, when burning a determinate volume in an hour. The London unit of illumination, which is that generally used elsewhere, is the light of a sperm candle burning one hundred and twenty grains per hour. The apparatus of Mr. Suggs consists first of a gas meter which presents two conspicuous index hands, one of which revolves once in a minute, while the other makes a complete revolution during the passage through the meter of one-twelfth of a cubic foot of gas. The first of these movements, being maintained by clock work, is constant. The second, being dependent on the velocity of flow, or what is the same thing, on the rate of burning, may be varied by varying the freedom of discharge. Since one-twelfth of a cubic foot of gas passes with each revolution, if the revolution occupies one minute there will pass one cubic foot in twelve minutes or five cubic feet per hour. As the parliamentary statute requires that the gas furnished by the London companies shall possess an illuminating power, when burned at the rate of five cubic feet per hour, not inferior to that of fourteen sperm candles consuming each one hundred and twenty grains of the combustible in the same time, this apparatus, combined with a Leslie photometer, makes the application of the test very easy. The gas, before entering the meter, passes through a governor, which maintains the burning pressure uniform, however variable may be the pressure in the mains. It is therefore easy, by means of a stopcock, to adjust the delivery so that the revolution of the volume index shall correspond exactly with that of the time index. A delicate balance accompanies the apparatus, by which the consumption of the candle used for the purpose of comparison may be accurately ascertained; so that the results of the experimental trial may be very expeditiously computed. This apparatus is designed of course for the use of gas-engineers, or for the officials whose duty it may be to test the quality of the gas furnished by the companies for the public consumption.

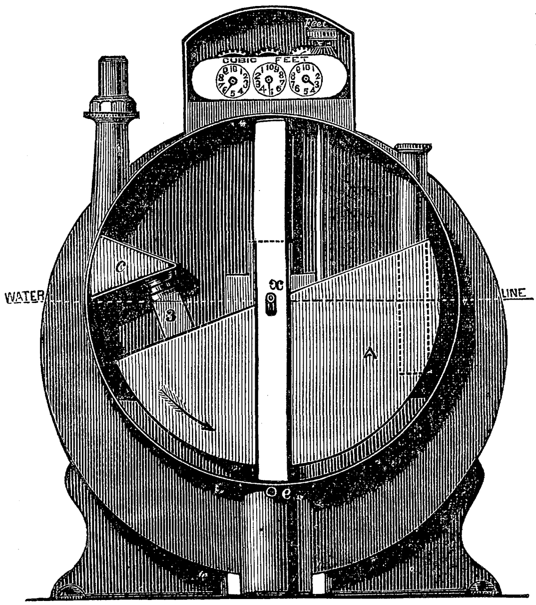
CONSTANT LEVEL METER.

The constant level meter manufactured by the London Gas Meter Company, is designed to prevent the inaccuracy of measurement to which the ordinary meters are liable, in consequence of the variability of the level of the water contained in the apparatus. Whenever the water is

too high, the error is against the consumer; when it is too low, the consumer is to a certain extent benefited. But from the construction of the instrument, for a given difference of level in excess or in deficiency, the first error exceeds the second very largely, and more largely as the difference is greater. The common meter is never an accurate instrument, except when the water is exactly at that level to which the system of counters is originally adjusted. The water in the meter may be increased or diminished by design, but it naturally wastes by evaporation with the progress of time. As the meters are wholly under the control of the companies, they will naturally charge them with a view to save loss to themselves by the effect of this natural process; and the consequence is that the meter will generally contain an excess of water; or that the time during which it is in excess will exceed that during which it is in deficiency. Yet if the periods of excess and deficiency were equal, the error on the whole would be in favor of the company.

The constant level meter is, as its name implies, an instrument in which the level of the water is maintained at the same invariable height by an automatic action of the apparatus itself. Since loss by gradual evaporation is what is to be chiefly guarded against, the expedient naturally employed to produce the compensation is a float. This invention is not the first in which a float has been introduced for the same purpose; but it is the first in which the compensation which it was the object of the expedient to secure has been effectually obtained. Some of the contrivances involving the use of the float have in fact been a source of greater inconvenience than that which they were employed to remedy. The float in the present instance is of a semi-cylindrical form and is contained in a cylindrical chamber attached to and communicating with the meter. The semi-cylinder turns freely on a central axis, which coincides in position with the surface of the invariable water level. The annexed figure illustrates the construction and movement here described. Immediately above the water level, on one side of the chamber in its interior, is a small projecting triangular or wedge-shaped box, into which the gas enters by an orifice on

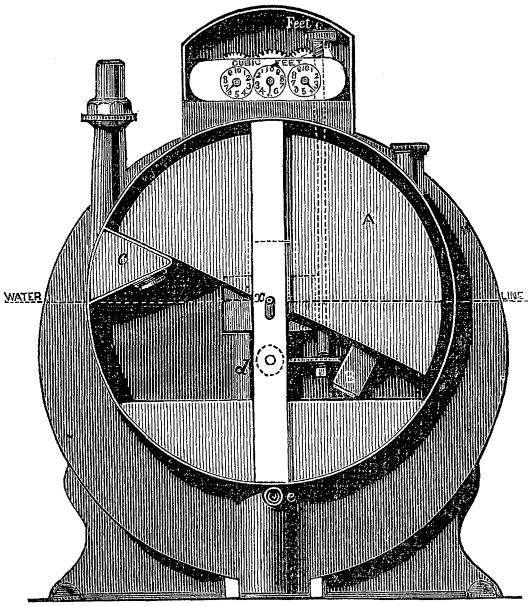
Fig. 74.



Constant Level Meter.

the under side of the wedge, just at the water level. When there is no water at all in the meter, or very little, the float occupies naturally, by gravity, the lower half of the chamber; but it carries on its plane side at the extremity which is thus brought immediately beneath the gas box just mentioned, a stopper, which enters into the opening which is the gas passage, closing it entirely and thus preventing further flow. If water is now introduced into the meter, the float, by its buoyancy, will gradually turn round its axis, reopening the gas passage and permitting the flow to go on again. The float turns, because, in the position in which it is arrested in its descent by the contact of its stopper with the gas box, its upper or plane surface is considerably inclined, owing to the length of the stopper. A greater portion of its bulk being then on the side of the axis opposite to the gas box, the upward pressure on that side will preponderate. When the meter is full, the float will assume a position nearly over the axis, but still with a small part immersed, since the gas box again arrests its movement before the plane side becomes horizontal. This position of the float is shown in the second illustrative figure. If an excess of water is introduced, it escapes immediately by overflow through a vertical pipe of which the upper extremity is exactly at the line of invariable water level. The escape of gas through this pipe may be prevented by recurving it at the lower extremity and filling the bend with water, or by allowing it to descend beneath the surface of water in another vessel. But as excess of water cannot be present except during the filling, it answers the purpose to leave the pipe open until the filling is complete, and then to close it securely. As the water wastes by evaporation, the float descends and immerses an increasing portion of its bulk, which is always exactly equal to the quantity of water which has disappeared. The level of the water thus remains always the same, and the rate of measurement of the meter is perfectly uniform.

Fig. 75.



Constant Level Meter.

III.—BOILER FEEDERS.

RIEDEL'S FEEDER.

Among the variety of contrivances for maintaining the water of steam-boilers at a uniform level which the Exposition embraced, there were two which belong to the class of meters as well as feeders, and which appear to be sufficiently novel to merit notice. One of these was an American invention exhibited by Mr. G. A. Riedel, of Philadelphia. Its principal organ is a large receiver for the feed water, in the form of an ellipsoid with its longest axis vertical. This receiver communicates with the boiler by means of two pipes, one of which descends into the water of the boiler nearly to the bottom and terminates above at the bottom of the receiver, this latter being placed at a higher level; while the other enters the boiler only to the proper, or rather minimum level, water line, and ascends to the top of the receiver. In the first-mentioned tube there is, beneath the water level in the boiler, a valve opening downward. This prevents the steam by its pressure from driving the water into the lower part of the receiver. Supposing the receiver to be full of water, and the water in the boiler to fall below the extremity of the shorter or gauge pipe, steam will enter this pipe and passing up to the top of the receiver will equilibrate the pressure upon the surfaces of the boiler and receiver water, so that the latter will flow into the boiler by its own gravity through the longer pipe. The water in the boiler being thus raised, the gauge pipe will be once more covered by it; and in this condition of things water is prevented from ascending in this pipe as well as in the other by an automatic contrivance. If the receiver become quite or nearly exhausted, its weight will be diminished, and at the same time it will be necessary to draw a new supply from the source. This latter object is accomplished by taking advantage of the diminished weight and of the fact that the steam which now occupies the place of the water which has been withdrawn, will by condensing form a vacuum within the receiver. This vessel is sustained by a balance beam carrying a kind of bracket resembling the bail of a kettle at one extremity, which embraces the receiver and lifts it by a pair of trunnions on its opposite sides. The other end of the balance beam carries a counterpoise. This beam is not pivoted at a fixed point in its length, but rests upon a roller in a vertical support, so that as the receiver rises, when, by the discharge of its water, it becomes too light to balance any longer the counterpoise, the relative length of the two arms of the lever varies with the movement. This movement takes place nevertheless about a fixed axis which is under the lever, and farther from the receiver than the roller support. This fixed axis is hollow throughout its length except at the central part. It is therefore in effect divided in the middle point by a permanent partition. One end of this tube communicates with the long or deep tube in the boiler, and the other with the short or gauge tube. And the con-

tinuation of these tubes to the receiver, as above described, takes place through the medium of these two opposite halves of the axis tube. The connections between the axis and the receiver, whereby this vessel is forcibly compelled to describe an arc having its centre in this axis, are, in fact, the tubes above described which provide for the circulation of the water and steam. They are therefore constructed of sufficient strength to give rigidity to the system; and, as will be inferred from the description, their direction is horizontal; so that in leaving the receiver they make a right angle.

This being understood, let it be supposed that the receiver has discharged its water into the boiler and is full of steam. The counterpoise now predominates and the receiver rises. In rising it acts upon two valves, one of which by closing cuts off communication between the boiler and the receiver through the gauge pipe, while the other opens a communication between the receiver and the source of water supply. The vacuum created by the condensation of the vapor is immediately filled by the water, which, giving once more the predominance of weight to the receiver, causes the system to tilt back into its original position. The ingenuity of the arrangement of parts by which the lever arm sustaining the receiver is automatically lengthened and shortened in the successive oscillatory movements appears in this, that when the receiver is filling, the arm which suspends it is at its minimum of length, so that it does not acquire weight enough to overcome the preponderance of the counterpoise until it is entirely full. On the other hand, when it has resumed the position which is determined by its own preponderance, the length of the arm is maximum, and it is impossible for the counterpoise to prevail until it is once more fully discharged.

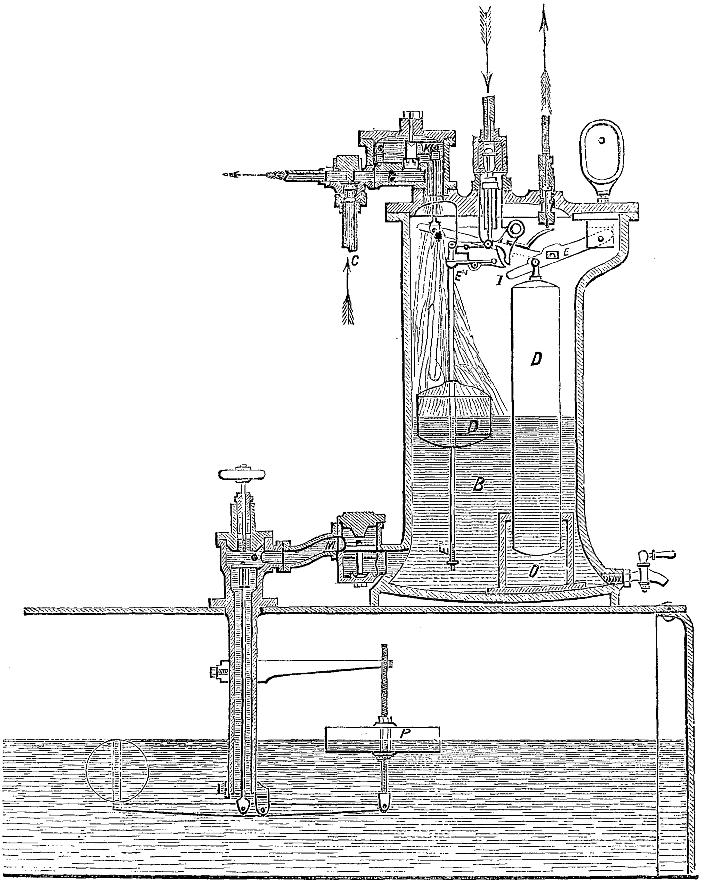
This apparatus serves admirably for feeding fixed boilers. As it is dependent on the action of gravity, it would not answer for engines on shipboard. One advantage attendant on it is, that, by the addition of a system of register dials, the quantity of water supplied in a given time may be measured, and therefore an exact account may be kept of the quantity of steam made.

HOUGET & TESTON'S FEEDER.

This contrivance, which serves equally, like the last, as a feeder and a meter, cannot be well described without the assistance of a diagram. It is shown in section in the accompanying figure 76. In the interior of the vessel are seen two floats, a large one D and a smaller one D′. The float D, in the condition of things shown, is maintained in its position, notwithstanding the rising of the level of the water, by the lever E, to which it is attached, and which is checked by the catch at the heel of the lever E″, which detains it at the point I. These arrangements will be more clearly understood by reference to the enlarged Fig. 77. The lever E acts upon another lever by a connection at E, which second lever, in the position represented, lifts the valve K, being pivoted at a point

not lettered, above E″. This same lever is capable also, when lifted by the lever E, of opening the valve L, and of closing the little valve not lettered, further to the right. This last valve is an air escape and

Fig. 76.



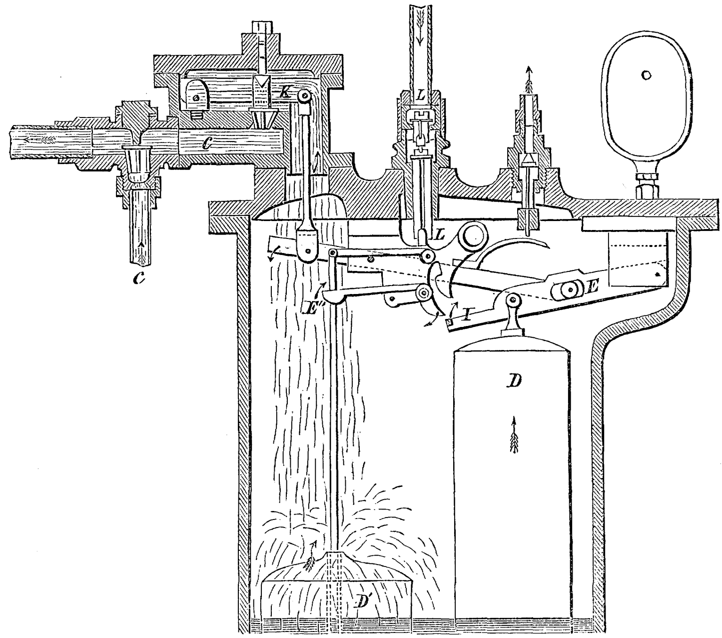
Houget & Teston's Feeder.

remains open while the feeder is filling, to prevent a back pressure from the confined air. The valve K, which is lifted in the position shown, admits water by natural descent from a source higher than the feeder, or as thrown in by a force pump. As the water rises it lifts the small float D′, which is guided by the vertical rod E‴. When the float D′ reaches the lever E″ it releases the extremity of the lever E; and the large float D being now completely immersed, ascends with great force, closing the valve K and the small air-escape valve, and at the same time opening the valve L. The valve L opens communication with the steam of the boiler, and thus equality of pressure is established on the surface of the water in both boiler and feeder. If now the valve O is open at the top of the tube communicating between the boiler and the bottom

of the feeder, the water will descend freely, lifting the light valve M, which is placed there to prevent an ascent of the water from the boiler into the feeder, in case O should be open when the feeder is in process of filling.

As the water falls in the feeder the float D will lose its buoyancy, so that if free to descend it would close the valve L and open the valve K,

Fig. 77.



Houget & Teston's Feeder—enlarged view of upper part.

in consequence of which the feeding process would be arrested. In order to prevent this a catch is fixed to a lever connected with the vertical rod E''' which hooks on to a stud at the extremity I of the lever E, and prevents the descent of that lever. The float D consequently remains suspended until the small float D' has reached in its descent the cross-pin near the bottom of the rod E'''. By the time that so much of the water of the feeder as can pass out through M has made its escape, the weight of D', which will then be nearly uncovered by the water, will be sufficient to operate on the lever by which the rod E''' is suspended, releasing the stud I in the lever E from the catch which detains it, and allowing the float D to fall. With the fall of this float the steam valve L is closed, and the water valve K is opened. The air-escape valve is also opened at the same time. The process of filling then recommences, and goes on as before.

The opening and closing of the valve O is determined by the float P, which is counterpoised while the water is sufficiently high; but when, by the descent of the level, P is left too far uncovered, its weight pre-

dominates and the valve opens. The valve may be fastened permanently down by a screw entering from above. The counter is placed on the top of the feeder. Its position is given in outline on the right. There is much ingenuity in this contrivance, and for fixed boilers it must be very useful.

CHAPTER VIII.

MACHINES AND MECHANICAL APPARATUS DESIGNED FOR SPECIAL PURPOSES.

MULTIPLICITY OF INTERESTING OBJECTS IN THIS CLASS—MACHINERY FROM THE UNITED STATES—SELLERS'S PLANING MACHINE—MACHINES FOR SPECIAL PURPOSES—ARMSTRONG'S DOVETAILING MACHINE—ZIMMERMANN'S-GANZ'S-WHITNEY'S GAUGE-LATHE—PERRIN'S BAND SAW—MACHINES FOR MAKING BARRELS, PENCILS, NAILS, HINGES, AND FOR DRESSING MILLSTONES—BRICK-MAKING MACHINES—MACHINES FOR CUTTING TOBACCO, FOR MAKING SHOES, CORSETS, CHENILLE, AND FOR FOLDING PAPER—CUTTING SUGAR—WASHING AND CORKING BOTTLES—MISCELLANEOUS INVENTIONS—ELECTRICAL DETECTORS—CLOTH-DRYING—SAFETY BRAKES—MECHANICAL BROOM—AUTOMATIC GRAIN WEIGHER—IMPROVED MILLSTONES.

INTRODUCTORY OBSERVATIONS.

The applications of machinery to the arts of life are so various, that an exhaustive report upon the objects present in a great exposition which properly arrange themselves under the title placed at the head of the present chapter, would be a very arduous undertaking, and would occupy a very large space. Nor is the preparation of a partial report an undertaking without its difficulty; since, amid the multiplicity of interesting objects offered to his choice, the reporter is often embarrassed which to select. The present writer is to a certain extent relieved of this embarrassment, by the consideration that it will be the province of other committees to take account of the machinery and processes employed in some of the most important departments of industry; while his own more general task is rather to notice only such as might be likely to escape their attention.

The notices embraced in the present chapter relate to such objects of the class thus indicated as excited at the time of their examination the strongest interest in the mind of the writer. It does not follow that there were not many other things equally worthy of record; but in the necessity of choice an individual must be limited to the range of his own observation and guided by such judgment as his knowledge of the matters observed enables him to form. It would have been well if the study of these very diversified and miscellaneous matters had been intrusted to a mechanical engineer or expert by profession; since personal experience and familiarity with industrial operations are surer guides to a correct appreciation of such things than any theoretic knowledge can be. In view of this fact the present reporter has sought

as far as possible the assistance of practical men, has availed himself of the descriptions (where they were obtainable) given by inventors themselves, and has borrowed to some extent from the notices of reporters to the different journals of practical science. Many of these journals were represented at the Exposition; but none of them more persistently throughout the continuance of the display, and none of them with more ability and judicious discrimination, than the London Engineering. The volume of that journal for 1867, in itself alone, embraces a more comprehensive and more satisfactory review of the Exposition, especially so far as Groups V and VI are concerned, than any official reports which have yet appeared. Its descriptions of the most important machines, instruments, processes, and products exhibited were elaborate, and its illustrations, which were given with profusion, were clear in their details and were admirably executed.

In the notices which follow, it has been no part of the design to enter into minute description. The character of each invention, the uses it may subserve, and the extent to which it promises to be, or has already proved itself to be, an improvement on previously existing forms of industry, or a contribution to productive power, are all which the objects of this report require, or which its limits will allow.

MACHINERY FROM THE UNITED STATES.

To an American it was exceedingly interesting and gratifying to observe, that while the space allotted to his country was actually small, the amount of ingenuity and originality which it embraced, especially as it respects the forms of machinery applied to the useful arts, was relatively very great. And while it was manifest to any one acquainted with the existing state of mechanical industry in the United States, that the country was very inadequately represented, it was equally obvious that, so far as it was represented at all, it was well represented. It was indeed worthy of notice, in reading the sketches of the Exposition contributed to the leading journals of the day, as well as to those devoted specially to the interests of industry, by their regular correspondents, how large an amount of attention was given to American machinery.

The number of American exhibitors of machine tools was quite limited compared with those of France and England, their principal competitors; but among the objects presented by these few were some of the most efficient of their kind and of the most original in their construction, which the Exposition embraced. Those of Messrs. Sellers, of Philadelphia, Brown & Sharpe, of Providence, and Bement & Dougherty, of Philadelphia, for working in metal; and those of Messrs. Rogers & Co., of Norwich; of Whitney, of Winchendon, Mass., and of Cool, Ferguson & Co., of Glen's Falls, were especially commended. The study of this class of machines has been intrusted to another; but

it may be permitted here to mention the compliment paid to Mr. Sellers by the jury, of the class, who pronounced his magnificent planing machine to be, "as well for its dimensions as for the novelty of its construction, the most important in the Exposition." Of its moving parts they add, "the guidance is perfect, and most of its automatic transmissions are new and very efficacious." And of the other machines presented by the same exhibitor, the acute observer who contributed the contemporaneous notices of the machinery of the Exposition to the London Engineering spoke at the same time in the following terms of high commendation:

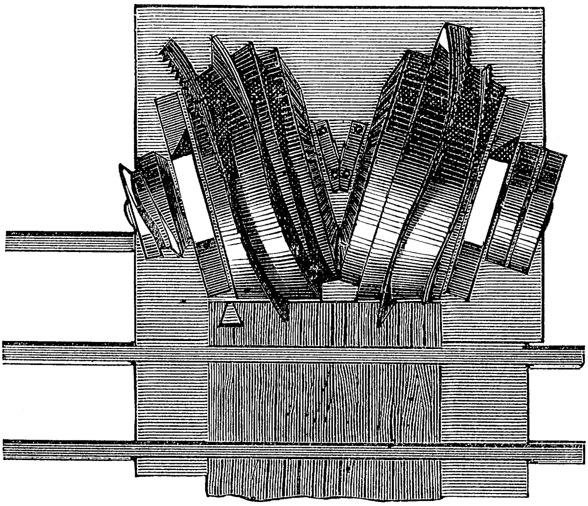
"The designs present a great amount of originality, and some of these machines, particularly the bolt-screwing machine, have found universal favor in European workshops. The other tools exhibited in Paris present a similar character. We note a small planing machine brought out by Mr. Sellers in 1860, and patented in this country, having its gearing from the driving pulley direct by a single pair of bevel wheels working a worm, the shaft of which is placed at an angle with the line of motion of the planing machine table, and working into a rack beneath. The self-acting motion for changing the strap for the return motion is placed at one side in a very compact form, and the tool box has a self-acting motion for lifting the tool off its work during the return stroke. Mr. Sellers's lathes are fitted with sliding carriages, having no compound slide-rest on the top of the carriage, but simply a cross-slide only on the top of the carriage itself. This necessitates the movement of the whole carriage by hand in setting the tool to its work, but it saves expense and simplifies the machine. The carriage has a sliding movement by rack and pinion, which is obtained from the fast headstock by means of frictional gearing between adjustable revolving disks. By changing the relative position of these friction plates it is possible to vary the rate of feed given to the sliding carriage with a constant speed of revolutions given to the mandril. The disks are pressed against each other by short spiral springs, and appear to afford a very handy method of adjusting the cut according to the requirements of the material operated upon. The smaller lathe of Mr. Sellers shows an adjustable tool-holder, which allows the turning tool to be set at different angles to the work, as is occasionally, but not very often, required. There are also adjustable stops provided for cross-cutting up to a given depth. Each of Mr. Sellers's machines has a box for storing tools in some part of its hollow framing. In the designs it would be difficult to point out any precise English original; there is nothing but the general mode of distributing the material, and the manner in which most of the details are constructed, which shows Mr. Sellers's really intimate acquaintance with English practice. In every other respect there is a decided originality about these machines, placing them upon a totally different level from mere imitations, and giving in many instances to Mr. Sellers the credit of having originated some of the most useful specialties of tools now to be found in English workshops."

I.—MACHINES FOR SPECIAL PURPOSES.

ARMSTRONG'S DOVETAILING MACHINE.

The Exposition contained four or five machines, all more or less ingenious, for performing the rather difficult work of making dovetail joints. Of these, the most expeditious in its operation, and as satisfactory as any in performance, was the American machine bearing the name of the patentee, Armstrong, of New York. Without complete drawings it would be impossible to convey an idea of the action of the machine in all respects; but the essential and most important part is shown in the figure annexed. It will be seen that there are two disks mounted on axes inclined to each other, as well as to the main driving-shaft, and revolving at the same speed, the one being inclined to the right and the other to the left, the motion being transmitted from the first to the second disk by means of bevel wheels cast on their inner surfaces. Each disk has on its outer circumference a spiral groove making one complete turn, into which is fitted a saw composed of segments, so arranged as in one complete revolution to give both the longitudinal and transverse cut necessary to finish a dovetail, one half being made by one disk and the other half by the other. The leading portion of the saw is composed of segments similar to those that could be cut from an ordinary fine-pitched circular saw, while to produce the transverse cut after the longitudinal one is finished the segments assume the form shown in the engraving, from an inspection of which the arrangement will be better understood than it could be from description. The saw which makes the cross-cut will be seen, in fact, to be placed like a belt or hoop on the circumference of the plane circular saw plate which forms the direct cut, and to widen gradually out to the breadth required for the cut. This hoop saw is not set at right angles to the plane saw, but at the bevel which corresponds to the angle of the joint. The segments which form the saws are held in their places by means of cast-iron cheek-plates held on by set screws with square heads, and in about one minute the attendant on the machine could change all

Fig. 78.



Armstrong's Dovetailing Machine.

the segments and replace them by others having a finer or coarser pitch of teeth if desired. To prevent the saws from splintering the wood on its under side, a longitudinal shallow cut is made by a knife-edge at the bottom of the dovetail before the helical saws operate on the wood; this is a most important point, and without it good work cannot be produced. The engraving above illustrates only the mode of forming one part of the dovetail. At the back of the machine provision is made for cutting the other part with equal expedition. An arrangement is also provided for raising the table so that the dovetailing can be done on a bevel if desired. The attendant was all day long besieged by crowds anxious to see this machine at work, and certainly he showed great patience in altering his machine to convince the sceptical of its wonderful scope and accuracy.

ZIMMERMANN'S DOVETAILING MACHINE.

Mr. J. Zimmermann, of Chemnitz, Prussia, exhibited a dovetailing machine in which three revolving cutters, having a form corresponding to that of the dovetail recess to be made, operate to cut simultaneously three recesses in the edge of the wood. The wood itself is placed on a horizontal table and moved downward before the cutters by means of a vertical slide to which the table is fixed. The three cuts being completed the slide has a horizontal motion sufficiently large to bring a fresh portion of the wood before the cutters, when the operation is repeated. For cutting the counterpart of these dovetails the same machine is employed, with plain revolving disks or cutters, the table being then placed in an inclined position, so that the vertical slide, in carrying the wood against the cutter, produces a parallel cut inclined in one direction; and at a second operation, for which the table is placed in an opposite inclination, the second bevel is produced. The machine has the advantage of being small and compact, and cheaper than some other dovetailing machines exhibited. Its only drawback is the multiplicity of changes required in setting the machine for doing the different parts of one operation before the work can be completed.

GANZ'S DOVETAILING MACHINE.

Still another machine for the same purpose was exhibited by Mr. A. Ganz, of Ofen, in Hungary. The following description may convey some idea of its operation, although without figures it is difficult to make it perfectly clear.

The novelty in this machine consists in its operating simultaneously upon the two wooden planks or boards which are to be dovetailed together, and in its producing the kinds of dovetails which form the counterparts of each other by the same action of one set of cutters. The machine consists of a pair of revolving disks, each fitted with a series of plain cutters at their circumferences, and geared together by means of bevel wheels, so as to revolve in two planes which form the

same angle as that intended to be given to the projecting dovetails. The board in which the recessed cuts are to be made, rests upon a horizontal bed, on which it slides immediately in front of the cutters. The two sets of revolving cutters are set sufficiently far apart to enclose between their planes of motion the width of two dovetails, so that one cuts the right side of one projection while the other produces the left side of the next following. In the next stroke or cut the board is moved forward with its carriage by means of a screw to the exact pitch of the dovetails, and a repetition of the same operation completes the second side of the projection last made, so that at each cut one dovetail is completed and the next following cut out on one side. The revolving tool advances through the wood vertically downward, or rather in an arc of a circle described by it round a fixed and rather distant centre. In order to effect this movement the cutters are mounted, not in a frame incapable of movement, but at the extremities of arms which are hinged at the opposite extremities, so that by the revolution of a cam the knife ends can be raised or depressed. Each revolution of the cam corresponds to one down-stroke of the two arms, or to one cut through the board. At the extreme end of the cut a fixed tool for cross-cutting is placed, which, in the descent of the cutter frames, clears the bottom of the dovetail and produces a smooth surface at that place. These movements complete the operations of the machine, but they are at the same time made use of in a very ingenious manner to produce the corresponding dovetails in the other board which is to be fitted to the first. This second board is fixed to the machine in a vertical position; that is, at a right angle to the board first mentioned, and in the same position in which it is to be fitted to the latter. In this position it is obvious that the revolving cutters make grooves into the second board exactly corresponding to the projections left on the first, and the two boards being once properly set against each other, the same cut of the revolving tools will produce the dovetails on the first and the corresponding grooves on the second board. The machine at the Paris Exhibition is the first of that kind made by Mr. Ganz, and is capable of being improved in some of its details, but as a whole it is well designed, and its mode of action is very ingeniously contrived.

WHITNEY'S GAUGE LATHE.

This is another American machine which attracted much attention at the Exposition for its effectiveness and its originality. It is the invention of Mr. Baxter D. Whitney, of Winchendon, Massachusetts, and is designed to turn out chair rounds, banister columns, and all similar objects in which the cylindrical form is modified by contraction or enlargement of diameter, the formation of beads, &c., so as to present curves or broken lines in its contour. Without the aid of drawings, it is difficult to make the construction intelligible in its details, but the general mode of its operation may be understood from the following explanation:

The rough piece of wood which is to be turned is placed between two centres, as usual. The centre next the driving pulley is formed in the manner of a serrated disk, so as to grip the end of the piece to be turned, and the other centre is formed with a central raised point and slightly raised rim all round the small disk which constitutes the end of the spindle. This centre is advanced or withdrawn by a screw and hand-wheel as usual. The wood in the lathe, supposing that it is to be turned to a figure of undulating or otherwise varied outline, is first brought to the form of a regular cylinder; and this is done by means of a fixed chisel in a slide rest, which is advanced on its bed in the same manner as any common slide rest, by means of a screw driven by a pulley. The slide rest, however, has two chisels in it, one of which is intended, as just stated, to reduce the wood to the form of a uniform cylinder, while the office of the other is to cut away the portions of the cylinder which must be removed in order to produce the varied outline which the design requires. This chisel performs its function in a comparatively rough way; the finish of the work being accomplished by a supplementary device presently to be explained. The manner in which this chisel is made to do its work will be understood when it is stated that the chisel-holder is hinged, and that a foot firmly connected with it rests on an iron rail or gauge, which is cut to the contour which the wood is to have. As the slide rest advances this foot rises on the swells and sinks into the depressions of the gauge; and the tool-holder, with its tool, rises and sinks with it, and thus transfers to the wood the precise contour of the gauge. There cannot, it is obvious, be a complete finish in this way, especially where there are sharp angles in the outline required. The steady advance of the chisel in the longitudinal direction would prevent the exact reproduction of these, and they would, moreover, interfere with the smooth sliding of the foot.

The final finish is therefore very ingeniously given by means of another tool, which is now to be described. Immediately behind the wood in the lathe is a vertical frame, which has a free motion up and down in guides; and to this frame is attached, at an angle of about thirty degrees to the axis of the lathe, a long knife with its cutting edge downward, extending the whole length of the piece of wood to be turned. This knife is moulded or corrugated also to the form of the design to be executed; so that, if an orthographic projection of it should be made on a horizontal plane, the projection of the edge would be the exact outline which the pillar, when finally completed, is to present. Now, if there were no sliding chisels, it is evident from this statement that the knife here described, supposing it to be brought downward on the wood as it turns in the lathe, might, provided it were strong enough, and provided that the wood were yielding enough, cut out the required column at once from the rough block. But as this operation would in general exact some force, the result would not probably be very satisfactory. It is preferable to bring the figure very nearly to the required shape and

dimensions before bringing down this guillotine knife; and then this, having little to do but to smooth the surface, will produce a neat finish at very little expenditure of force.

One important part of the mechanism, which has not been thus far mentioned, must not be overlooked. The slide rest carries an arm and circular gauge, this latter having the exact diameter of the cylinder turned by the fixed chisel, and intended to follow over the wood as fast as it is turned to the cylindrical form, in order to steady it during the subsequent operations. During the process of fixing the wood in the lathe, this gauge admits of being run back over the movable centre out of the way.

It remains to be explained in what manner the diagonal guillotine knife is brought into action. The frame to which the knife is attached is counterpoised in such a manner that it requires but little force to move it either up or down. It has also a diagonal bar at a lower level than the knife but parallel to the latter, which carries a projecting flange presented toward the slide rest. A notch in the rest, or in an arm connected with it, is adapted to this flange; and as the rest moves along horizontally while the flange is inclined, the knife is brought gradually down. Thus it may happen that upon different parts of the same column, the fixed chisel may be reducing the rough surface of the original wood, the movable chisel may be doing the heavy work of reduction to the required contour, and the descending knife the light work of finishing, all at the same time. Of course a different knife and gauge rail will be required for every different pattern of pillar. But the other parts of the mechanism will remain without alteration, whatever bulgings or mouldings are employed. For the purpose for which it is intended nothing can be more rapid and efficient than this lathe, and a similar device might with advantage be introduced to form the bulging pillars of balustrades in stone in all cases where a large number of them is required.

Beside this lathe Mr. Whitney exhibited several other machines for working in wood, which were complimented by the discriminating reporter for the London Engineering, as being "all novel in their principles of construction, original and elegant in their design, excellent in workmanship, and perfectly successful in their performance." He adds: "They may be considered as model types for study and imitation, and they have earned the approval of every competent visitor to the Exhibition."

And in regard to one point of special interest he goes on to observe: "There is one important feature in the construction of these machines to which we are desirous of drawing attention, as it is a question of principle rather than one of detail. Whitney's machines are constructed with a remarkable economy in weight. The frames are in appearance and in reality considerably lighter than anything that could be designed by our first-class makers of wood-working machinery; and

yet these machines show no trace of vibration in working and are proven to be of ample strength by their performance. We have heretofore noticed the fact that the modern tendency in the construction of wood-working tools is to reduce the dead weights; and we are glad to find in Mr. Whitney's machines a practical illustration how much more is yet to be done in this direction, an illustration which we believe will not be lost even upon those among our machinists who are the most anxious to insure solidity and strength by the profuse application of massive and heavy castings. With scientific designs and excellence of workmanship, we have no necessity for the application of heavy masses for machinery which runs at such very high speeds, and has so little direct strain upon its working parts as the generality of wood-working tools."

This critic pays a compliment to our country in general in respect to this branch of industry, in saying that European engineers had looked forward to the exhibition of wood-working machinery in the American department with unusual interest, regarding America as "the natural home and native land of this kind of machinery;" since the United States had furnished the first models of the most important wood-working tools in general use in Europe; and since these tools, however modified in details, still preserve everywhere their distinctive principles and main features of construction, "just as they were transmitted to us across the Atlantic." He says, indeed, that even yet British and continental artisans are accustomed, whenever a new desideratum in wood-working machinery makes itself felt, to look to America to furnish the desired relief; and that they even continue to be occasionally surprised by the appearance of a new tool from the "States" before they are aware that they want it; though they very soon learn to appreciate the value of the present after giving it a trial.

PERIN'S BAND SAW.

The substitution of the circular for the reciprocating saw was a very important step of improvement. It introduced a considerable economy of the force employed, and a still larger economy of time. The reciprocating saw occupies as much time in rising as in descending, and is therefore effective only during one-half the period of the operation. But the continuous action of the circular saw is attended with the additional advantages that it can be run at a higher rate of speed than is possible for the older form, and that it admits of a heavier feed on account of the steadiness and regularity of the continuous cut.

These advantages have been secured for the saw with a straight edge, by Mr. Perin, of Paris, by giving to the tool the form of a band running over pulleys of diameter sufficiently large to allow the material to be operated upon to meet the saw on the descending side, without being interfered with by the part which is rising. The saw must of course be made of very flexible steel, and it is therefore comparatively thin. On its first introduction some disadvantage was experienced from this circumstance,

on account of its unsteadiness. This, however, has been overcome by the simple expedient of placing a fixed guide, which is nothing but a piece of wood having a slit in it equal to the thickness of the saw, immediately above the material which is to be cut. A similar guide is also usually placed below.

These band saws are constructed of various sizes, some of them sufficiently large to cut heavy timber. But the most interesting forms are those of which the breadth is hardly greater than that of a watch spring. These are used to cut out scroll work, a function which they perform, whatever may be the degree of delicacy or intricacy of pattern, with surprising rapidity. Such saws were exhibited in both the British and the French sections of the Exposition, and were constantly occupied in cutting out fanciful patterns for the gratification of visitors. Scrolls and spirals were cut out of blocks of hard mahogany four or five inches in depth, with very sharp curves, and of a thickness not exceeding that of very thin card-board. The initials of the names of visitors were cut with great rapidity, in a very graceful script, and objects of this kind seemed to be especially popular. The object and the matrix are equally perfect; and owing to the very slight thickness of the tool, the one fits neatly into the other and presents the pattern in relief. The band saw in this form is thus a very important addition to the resources of the ornamental worker in wood; surpassing immensely in precision, as well as in rapidity of execution, any similar tool used in the hand. It is destined, doubtless, to come into very extensive use.

When first introduced, this tool was not an immediate success. On account of the inequality of temper, or want of uniformity of quality of the steel, fractures were frequent. The welding of the two extremities which was necessary in forming the band, however carefully performed, presented always a point of insecurity. Experience has, however, suggested means of overcoming these difficulties, and at present fractures are of rare occurrence. It is considered, nevertheless, to be a judicious precaution against injury from such possible accidents, to surround the saw with a wooden box or shield, at least as high as the head of the workman. The pulleys are covered on their circumferences with leather, and the necessary tension is produced by adjusting screws, by which the distance of the two pulleys from each other can be varied. Some constructors, however, employ springs, or even weights, to maintain the tension.

In the British department the machine exhibited was provided with a table or bed susceptible of being inclined, so as to vary the angle at which the material is presented to the saw. The same object could be secured, of course, but less conveniently, by inclining the material upon a horizontal bed, and blocking it up in such a position. Some of the French constructors have even contrived to make the position of the saw itself variable, giving it at pleasure a vertical or inclined position while the material remains undisturbed upon a horizontal bed. Either of these

two expedients contributes very much to increase the usefulness of the machine. The velocity with which the saw runs is very great, being as high as fifty feet per second; yet its motion is so steady and silent that, to the spectator, especially in the case of the narrow scroll saws, it hardly seems to be moving at all. It needs only to be added that the *feed* is not intermittent, as in the case of ordinary saws, but is uniform and smooth, like the motion of the saw itself.

BARREL-MAKING MACHINERY.

Another of the very original contributions of the United States to the machinery department of the Exposition consisted of the machines, three in number, exhibited by Messrs. Cool, Ferguson & Co., of Glen's Falls, New York, for making casks and barrels. The three operations performed by these machines are—first, the cutting of the staves to the required length, finishing the ends, and providing them with the necessary groove for the introduction of the head; secondly, the finishing of the sides of the staves, for which purpose a number are firmly held together, and subjected to the operation all at the same time; and finally, the formation of the heads to the proper size and figure, and with edges suitably prepared to enter the grooves in the ends of the staves. The advantages afforded by these machines over the hand manufacture of casks, are not simply economy of expenditure and saving of time. The article produced is much better than the hand-made article. It is easy, indeed, to perceive that the perfect uniformity of parts secured by the machine, and the perfect similarity of joints, must greatly improve the accuracy of fitting, and render the cask more solid, less liable to leak, and more durable than can be the case where, as often happens, the imperfection of workmanship is only masked or concealed by an excessive strain upon the hoops. The machines exhibited found, it is said, a prompt sale in France, having been purchased for the use of an establishment manufacturing Portland cement.

PENCIL-MAKING MACHINE.

The pencil-making machine of C. B. Rogers & Co., of Norwich, Connecticut, deserves mention for its ingenious adaptation to the object for which it is intended. This machine performs all the successive operations required in this manufacture with the utmost precision; commencing with planing the wood, cutting subsequently the grooves for the lead, and finally rounding and finishing off the pencil and turning it out complete.

The pencils are made six at a time. The machine is first used for planing and squaring small boards, each representing six pencils, which are to be cut from it. One set of these square boards is of a sufficient thickness to receive the groove for leading, and the other set is thinner, so as to be glued over the leaded board and to complete the pencil. The grooving is done by the same machine, which is fitted with a pair of

revolving cutters. There are six projections on the cutters, which produce the six parallel grooves. The lead is then inserted into the grooves, and the thin board glued over the whole, so that the six pencils are now represented by two square boards containing six bars of graphitic substance between them. The cutters of the machine are now again exchanged for one with six half-round grooves, which forms the six round pencils, when the board is passed through, first with its upper, then with its lower surface next the cutters. The cutters are made in halves of a complete cylinder, so as to facilitate their being properly sharpened; they obtain their clearance by being set eccentric to the axis of the rotating spindle which contains them. The exchange of cutters for the successive operations just described is intended to take place only after a large quantity of work has gone through one of the respective stages of manufacture; and for large works it would be necessary to provide several machines, each used only for one distinct part of the process.

This machine attracted much attention and admiration on the part of visitors; and for its great merit, together with that of his other excellent machines for wood-working, Mr. Rogers was awarded by the jury the honorable recompense of a gold medal.

WICKERSHAM'S NAIL MACHINE.

One of the most interesting and novel of the machines for special purposes which the Exposition contained was the machine of Mr. Wickersham, of Boston, for the manufacture of cut nails. For many years there has been very little advancement made in the machinery for this manufacture. Previously to 1807, the process of nail-cutting was rude and slow; but about this time a machine for making cut nails was invented by Mr. Jesse Reed, of Massachusetts, which, both in regard to rapidity of production and to the quality of the product, was the source of an immense improvement; and it is Reed's machine which is now in general use. The cost of producing nails was reduced by Reed's machine to one-tenth of what it had previously amounted to.

The machine of Mr. Wickersham is destined to make a revolution in this manufacture which may possibly prove to be no less important than that which followed the introduction of the earlier invention just mentioned. It produces a nail which is pointed like a chisel, and being tapered through its whole length, is much better than the old one for use; being more easily driven and holding more firmly in consequence of its breaking the fibre of the wood so little that it clings strongly and uniformly the whole length of the nail.

Heretofore, the plate from which the nails are cut has been made only equal in width to the length of a single nail. The machine would therefore cut but one at a time. In the Wickersham machine a sheet of metal from twenty to twenty-five inches wide presents its edge to a series of cutters, which cut simultaneously a row of nails, more or fewer in number according to their length, from the entire edge of the sheet. It is an

important feature of the machine that it economizes the metal so that the waste is reduced almost to nothing. The nails are cut out perfect and headed all at one operation.

The amount of work which this machine will do in a given time is very extraordinary.

In cutting half-inch patent brads or shoe-nails from a twenty-inch plate, there is a series of forty nails cut at each stroke of the knives, or one hundred and sixty per second, the machine driving the knives four times per second. Of patent brads from three-eighths to two inches long, and shoe-nails of all sizes, one machine will cut three thousand six hundred pounds per day. Of the larger sized nails, say of six to twelve penny nails, one machine will cut five thousand pounds, and of ship spikes one-quarter to three-quarters of a pound each, one machine will cut twenty-five thousand pounds per day of ten hours.

The machine consists of an iron stand or table, from which projecting frames rise to hold the head-piece that carries the cutters. This head-piece rocks on side bearings, and from the back of it project two short arms, to which a connecting rod is attached by means of a pin passing through them, and which communicates a rocking motion to the cutter-holder from a crank in the driving-shaft, which gives a stroke of three and a quarter inches. To one end of the crank shaft is fastened a pinion, which gears into a cog wheel having twice its number of teeth, and which therefore makes but one revolution to two revolutions of the pinion. On this cog wheel is a double-cutting cam for giving a lateral motion to the iron plate from which the nails are being cut. Just above this cam, and held in brackets projecting from the side of the frame, is a shaft, from one end of which depends a small crank, the pin of which works into the cam above referred to; and rising from it perpendicularly are two levers, which, by means of two connecting rods, communicate the lateral motion to the feeder. The feeder consists of a rectangular framework of iron, resting on two lateral guide bars moving in small studs projecting from the table of the machine frame. On the hinder guide bar is cut a small tooth wheel, and to it is attached a ratchet wheel, which is worked slowly forward by means of an arm attached to the pawl, which passes over a cam as the feeder receives its lateral movement. Working in grooves in the sides of the rectangular framework of the feeder is the feeder itself, to the forward part of which the iron plate from which the nails are to be cut is securely fixed by a small vice, and on the under side of the back projection of the feeder is a long rack working over the small tooth wheel cut in one of the lateral guide bars.

The cutter-head has ten cutters fitted into it two and seven-sixteenths inches wide, that being the length of the nails being made. These cutters are set alternately at different levels, the first, third, fifth, seventh and ninth being placed about a quarter of an inch behind the others; and every other cutter in each set is alternately placed at a different angle for the purpose of giving the proper shape to both sides of the nail; thus,

for instance, the first and third cutters would be employed in making one nail, the first giving the proper shape to one side of it, whilst the third completes the nail by cutting it from the plate and giving the proper shape to its other side. Similarly the third and fifth cutters also act together, the second and fourth, the fourth and sixth, and so on; and the nails are so formed that they are cut alternately with their heads in opposite directions, the piece that is detached for forming the head of one nail resulting in the formation of a pointed end to the next one to be cut out; so that the nails if arranged on a table in the same order as cut would reproduce the original plate. The cutters are so made that they slightly compress the nails in cutting, thus preventing raggedness or twisting.

As soon as one set of nails has been cut out and the cutters are raised, the cam on the large tooth wheel, working through the armature and levers attached to the side of the machine, pushes the iron plate sideways for a distance equal to the length of two nails; and at the same time the small ratchet wheel on the feeder, by causing a partial revolution of the small pinion on the guide bar, gives a slight forward movement to the plate equal to the thickness of the nail to be cut. Immediately after another cut is completed and the cutters raised, the cam again comes into play and draws the plate back again to its former position; a similar forward feed again takes place, and another lot of nails are made. Thus it will be seen that two more cutters will always be required than the number of nails to be made at each stroke; and in the machine at the Paris Exhibition, which makes eight nails per stroke, ten cutters are necessarily employed.

EVRARD AND BOYER'S HINGE-MAKING MACHINE.

A most remarkable machine, considering the nature of the work which it performs, and the surprising rapidity with which it does its work, was exhibited in the French section by Messrs. Evrard and Boyer, of Paris, for making brass butt-hinges for doors. The material is placed in the machine in coils, there being two coils of sheet brass for the two halves of the hinge-body, and a coil of wire to supply the connecting bolt or rivet. The material is drawn off from the coils as it is wanted, the wings of the hinge are stamped out by punching dies to the proper shape, the salient parts, which are to form the tube for the connecting bolt, are formed upon the wire itself which is to furnish the bolt, and this is then cut off to the proper length. Before the hinge is dismissed, the screw-holes, by which it is to be secured to the wood, are formed and countersunk to the form of the screw-head. The machine in operation at the Exposition threw off a complete hinge every second. A large variety of patterns were exhibited along with the machine; and the manufacturers keep a number of the machines of different sizes constantly in operation at their establishment, 7 Rue du Faubourg du Temple, Paris. The quality of the hinges compares very favorably

with that of similar articles manufactured by the ordinary and slower methods. On the whole this is one of the most remarkable examples of the economy of machinery which the Exposition contained.

MACHINE FOR DRESSING MILLSTONES.

A machine for preparing the surfaces of millstones with the regular teeth or notches necessary for effective grinding was exhibited by Mr. A. Morisseau, of Montargis, and appeared to perform its work very well. As the notches are to be cut in lines radiating from the centre, a central axis is fixed to the stone, the surface having been first made smooth and the large indentations having been cut in it by hand. The axis carries a radial arm which supports the tool to be employed in the dressing, and this tool is raised and dropped by a cam. After each blow the tool advances its own breadth along the arm, and the stroke is repeated. The force of the blow, or the depth of the cut, is regulated by an easily managed adjustment. The arm carries an apparatus for sharpening the tool, consisting of two rapidly rotating emery wheels, between which the edge may be passed without removing the implement from the machine. When one radial line is completed the arm has a slight movement of rotation, and another is commenced. The cuts produced by this machine have the advantage of those made by hand cutting, of being much more uniform and well executed. In addition to this the process is greatly more expeditious, and therefore, whereever the construction of millstones takes the character of a manufacture, it has the recommendation of superior economy.

BRICK-MAKING MACHINES.

The number of machines for the manufacture of brick is constantly increasing, and the great superiority of the product which they turn out, combined with the rapidity of production, is likely to secure for machine-made brick the command of the market to the entire exclusion of any other, except in situations remote from the great centres of commerce or the great channels of transportation. These machines may be distinguished into two classes: the first including those in which the bricks are moulded from plastic clay, and the second those in which the material is employed "dry;" by which term, however, it is meant only that the material is used with such small amount of water as it naturally contains when taken from the earth. In fact, when the clay is literally dry, some moderate degree of moisture must be artificially imparted to it; and this is accomplished, in Wilson's British process, by passing the material through a steam-chamber. On the other hand, when the season is wet, or when the natural source from which the clay is derived is always wet, it is necessary to diminish the amount of moisture; an effect which is most easily secured by keeping a supply of dry clay under cover to mix with that which comes from the bed too highly charged with moisture.

For the purpose of forming solid brick for building, the dry process is preferable, on account of the facility and safety with which the moulded masses may be handled immediately as they come from the moulds, without being liable to be deformed or distorted; and also because of the saving of the time which must be allowed, in the case of the wet moulded-brick, for drying. This drying process is moreover attended with a necessary exposure to the weather; and rains very often occasion serious damage when they occur during its continuance

GREGG'S BRICK-PRESSING MACHINE.—At the Exposition of 1867 the machine which seemed to be most in favor was that of Mr. Isaac Gregg, of Philadelphia, in which the brick are formed by the dry process with great rapidity. This machine was doubly exhibited, being presented in model in the palace, and in actual operation in the neighborhood of the Champs de Mars, during all the period of the Exposition. The material, after being screened and crushed, is elevated into a hopper, from which it is admitted alternately on opposite sides into the moulds, where it is powerfully compressed and delivered directly to the attendants to be conveyed immediately to the furnace. The brick, after burning, present a perfectly uniform and compact appearance. Their surfaces are smooth, their forms entirely regular, and their tenacity remarkable.

DAVID & COMPANY'S BRICK MACHINE.—Messrs. David & Co., of Havre, exhibited another dry moulding machine, in which moulds carried by a rotating table receive the clay successively as the table turns; each mould afterward coming under the action of a piston adapted to it in form, which compresses the clay to the necessary degree. The bottom of the mould is removable, and the brick, after compression, is withdrawn below. The rate of delivery is as high as fifteen hundred per hour.

The pressure exerted in moulding, it is stated, should be according to the nature of the earth used. When this is unctuous and damp, the pressure will not require to be considerable. When it is dry and incoherent, the pressure will require to be greater. Thus ten kilograms per centimetre of surface will be a pressure proper for some earths, but too great or too small for others. This machine, it is stated, will produce bricks of from fifty-four to seventy millimetres (from two to three inches) in thickness. An engine of four horse-power will be sufficient to drive it, and the labor required to utilize its performance may be labor quite unskilled in the work of brick-fields.

DURAND'S BRICK MACHINE.—Mr. F. Durand, of Paris, exhibited still another dry-moulding machine. In this the earth is thrown into a hopper, at the bottom of which is a square piston which compresses it in successive charges into a mould immediately beneath by a horizontal motion. The bricks, as they leave the mould, are deposited on an endless way, which carries them off to the place where the attendants are stationed to remove them. By a peculiarity of the mechanism, the pressure, which at first gradually increases, becomes very energetic at the last moment. The number of brick delivered per hour is said to be fifteen hundred.

ALLEMAND'S BRICK MACHINE.—Still another machine operating on the same principle was exhibited in the French department by Mr. Allemand. In this a long series of moulds are carried successively under the compressor in an endless band, the moulds themselves conveying away the bricks after compression.

HERTEL'S PLASTIC-CLAY BRICK MACHINE.—Quite a variety of machines were exhibited in which clay in the plastic form is the material used. Of these a very striking one was from Nienburg, in Prussia, the invention of Mr. Hertel. The description of this machine, as given by the inventor, represents it to consist of: First, "a plain flatting mill or cylinder for common clays, and of a double one for hard and stony ones. These rollers not only roll the clay, but grind and crush all the hard matters therein, the whole passing off in thin slabs or films to the horizontal plug mill placed beneath. Secondly, in the inside of the horizontal plug mill rotates a screw formed of intersecting blades of a new and special construction, which cuts and mixes the materials, at the same time conveys them into a compartment in which they are subjected to great pressure, and from thence pass through openings in the mouth piece, ready moulded and forming the products desired. When the machine is applied to manufacturing either solid or hollow bricks, a compound homogeneous mass or stream sufficient to form four bricks is at once and in a continuous manner expressed through the plate die. This mass in travelling along is carried on a slide, and is separated longitudinally into four parts by steel wires operating by the action of the machine. Thirdly, the cutting apparatus on said slides, which separates crosswise in a regular right angle the four said parts so as to produce at once four perfect bricks, which are removed from the slide after each movement of the cutter. This operation is done while the stream of clay is continually advancing."

They also claim that "this machine has solved an important problem, viz: the manufacture of bricks and other ceramic products possessing all the various qualities desired, by using either rich or poor clays, and either arable or stony;" and add that, "in fact, the calcareous bodies, limestone and silex, are so ground and reduced to powder as to neutralize their disadvantageous effect. The mixture of sand and cinders with any clay is, under the action of this machine, rendered quite homogeneous."

The rapidity of manufacture is not, however, quite so great as in the case of the machines above spoken of. Of solid brick, and of rectangular hollow brick, there are delivered from one thousand to one thousand five hundred per hour; of flat tiles two thousand to three thousand; and of drain pipes and mouldings, variable quantities according to size.

These hollow bricks are formed in the same manner as lead pipe, by being expelled through a die with a solid core. They have a degree of solidity unusual with moulded bricks made from wet clay. The quantity of water used is in fact only so much as is necessary to insure plasticity, so that the clay is very stiff before compression, and the bricks come from the die firm and solid so as to permit their being piled up immediately to a height of six bricks superposed edgewise.

The whole apparatus requires the attendance of three men; one for introducing the raw material, another for cutting off in desired lengths the plastic mass or the continual stream of solid clay on its issuing from the plate die, the third for the removal of the bricks or objects formed.

The motive force to be used varies from eight to twelve horse-power.

BOULET BROTHERS' BRICK MACHINE.—There were present at least seven or eight other machines for moulding bricks and tiles from soft clay, all having their merits. That of Boulet Brothers, of Paris, appeared to be very efficient. In this the pressure is given by an eccentric, as in a punching-press acting upon a die or mould. Also a machine for making hollow brick, in which two plungers, fed from two hoppers, force a bar of clay out at each end, these bars being cut in half by intervening plates of iron before the clay issues from the machine, so as to render the thickness suitable for a brick; also with proper fixed mandrels to make the bricks hollow, the stream of clay being formed with longitudinal channels in it by these mandrels. The clay riband is cut into the lengths proper for bricks by bringing down over it a frame with proper cutting wires.

SCHMERBOR BROTHERS' BRICK MACHINE.—Schmerbor Brothers, of Mulhouse, also exhibited a machine in which the clay, after being crushed between rollers, somewhat in the manner of Hertel's, was expelled in a continuous rectangular mass, which was cut by wires into proper lengths for brick, very much as is done in the analogous machine just mentioned.

CAZENAVE & COMPANY'S, SCHLICKEYSEN'S, AND SCHLOSSER'S BRICK MACHINES.—Cazenave & Co., of Paris, exhibited two machines belonging to this class—Mr. Schlickeysen, of Berlin, one, and Mr. Schlosser, of Paris, one. In these two last the clay is ground and tempered by means of vertically revolving helicoidal compressors.

BORIE'S BRICK MACHINE.—Mr. Borie, of Paris, exhibited a machine for working soft clay, which was provided with contrivances for rejecting pebbles and other solid bodies from the mass, and which was capable of not only forming hollow bricks, but hollow rectangular tubes, large enough for wall flues or even for chimneys of moderate size. His largest tubes are thirty-two inches on the longer side, and twenty-four on the shorter side of the rectangle.

HOGLEN AND GRAFFLIN'S TOBACCO-CUTTING MACHINE.

Messrs. Hoglen & Grafflin, of Dayton, Ohio, exhibited a machine for cutting tobacco, which seemed to possess the united merits of great rapidity of action and remarkable thoroughness of work. To this it may be added that the machine is easy of management, and that it economises material as well as time. The construction of this machine can hardly be made clearly intelligible without figures, but the mode of its operation may be concisely described as follows:

The tobacco which has to be cut is placed in a wooden trough with its bottom formed of an endless web, which advances it to the pyramidal feeding mouth, where it is caught by two endless webs of brass plates

connected by pitch-chains which gripe the faggot of tobacco above and below, and simultaneously propel it through the narrowing mouth until it issues at the throat, sufficiently compacted to be readily cut by a pair of rapidly revolving blades. The length of the pieces into which the tobacco is cut is regulated by altering the rate of the feed, which is done by changing the system of gear-wheels by which the mass is advanced.

Such a machine as the one exhibited will cut from one thousand five hundred to six thousand pounds of tobacco per day, according as the shredding is finer or coarser. When the tobacco reaches the knife, it is compressed into a hard mass of one-fourth the original bulk at the feeding mouth. A wooden drum is attached to the part at which the knives revolve, where the shred tobacco is collected and withdrawn through a drawer. As the feed is continuous, there is less loss by butts than when it is intermittent, and less loss by shorts in dressing. The rapid action also obviates any darkening of the color by heating, and the compressed mass can be run backward when the knives are being adjusted, which saves loss by swell. The machine is rapid in its action, and is in all respects highly efficient. The weight of the machine is three thousand pounds, and it requires a motor of four horse-power to drive it. The discharge mouth measures four inches by ten; the knife makes from eight hundred and fifty to one thousand revolutions per minute.

SHOE-MAKING MACHINES.

Shoes fastened by pegs or nails have long been manufactured on a large scale in the United States; but in general, if not universally, the work has been done by hand. Since the year 1844, screws have been employed more or less extensively in France for the same purpose; and machines have been gradually introduced to replace manual labor in different parts of the process of manufacture, until at length, in many large establishments, hand-work is dispensed with altogether. The French department of the Exposition presented a number of very interesting examples of shoe-making machinery; and one house, that of Dupuis & Co., of Paris, illustrated the whole process of manufacture from the beginning to the end. Machines for securing the soles by means of screws were also exhibited by Messrs. Lemercier, Brice, Cabourg, and others, differing in some of the details of their construction, but all performing their work with admirable rapidity.

The machines exhibited by Dupuis & Co. formed a complete series, by the successive operation of which a pair of shoes could be produced from the raw material in from one to two hours. The leather is cut into shape by means of tools resembling punches. The thicknesses which are to form the soles are united with glue and compressed previously to being cut. They receive then the necessary concavity by powerful hydraulic pressure; and their surfaces are smoothed and hardened in still another machine. Sewing machines form all the necessary seams,

binding, and, if necessary, ornamental stitching of the upper leathers; and then the separate parts are brought together in the important machine which is to complete the shoe by uniting the upper leather and the sole.

First, there is placed upon the form or last in this machine the inner sole. The upper leather is then stretched over this by means of small nippers attached to the machine, which are capable of stretching it with considerable force. It is secured in place by a row of small nails. The outer sole is then carefully applied over the whole. As this has been entirely finished and polished on the edges in the previous process of preparation, it is important that it be truly adjusted, since it cannot be afterwards trimmed. The machine then applies to the two soles, with the upper leather included between them, a force of pressure of not less than three hundred kilograms, increased, if desired, to one thousand kilograms, or one ton. Screws are then inserted all round the margin of the sole, an operation completed in the most rapid machines in less than three minutes for a single shoe, or in five minutes for a pair. The salient extremities of the screws are cut by a chisel, and the burr left by the chisel is ground away on an emery wheel. The last on which the shoe is constructed being made of iron, prevents the interior extremities from passing the surface of the inner sole.

The machine is provided with an indicator, by means of which the exact distance desired between the screws may be easily preserved. For different sizes and kinds of shoe this distance will vary, as well as the size of the screw itself. Any kind of shoe may be made in the machine, from the coarsest boots to the thinest dancing pumps.

An important feature in these machines is, that they not only apply, but make the screw. The material is brass, which is drawn off from a bobbin in the machine as it is required. The extremity passes horizontally through a guide, and, in order to cut the thread of the screw, the whole bobbin revolves. In hand machines a crank serves to give the revolution; but the driving power may be taken from a motor. When the resistance shows that the screw has struck the iron last, a cutter is brought into action by the foot of the operator pressing upon a pedal, and the wire is cut as near as possible to the leather.

Screw-fastened shoes are becoming more and more generally used in France. They cannot fail soon to replace pegged shoes everywhere, since the fastenings are much stronger and more durable, while the rapidity of the manufacture must greatly surpass that which is attainable in the use of wooden pegs. Whether they will equally supersede sewed shoes remains to be seen.

CORSET-WEAVING MACHINE.

The Convex Weaving Company of New York exhibited a very ingenious invention in the form of a machine for weaving corsets for ladies. Though the design of the invention was thus special, and though it is

thus far, it is believed, confined to weaving the articles above named, it is, nevertheless, capable of being applied to every variety of fabric which it is necessary to adapt to a figure of undulating contour or varying dimensions. Thus a waist for an external garment or a coat for a man might be woven on this principle with similar facility. It may be a question whether dresses could be made as elegant in this way as from stuffs woven in the ordinary loom and afterwards cut and fitted; but there is no doubt that they could be made entire in any form without seams. The corsets are not only made complete in form, but they are also furnished with the tubular spaces or channels required for the introduction of whalebones. The machine is capable of making forty pairs of corsets in ten hours. The following is the inventor's description:

"The principle of a constant length of travel for the shuttle was adopted for the sake of simplicity; but as it is necessary, in weaving the gores, that the weft thread should pass through only a part of the breadth of the warp, the Jacquard has been employed for the purpose of taking up the portion of the warp required to be woven in that part. As the shuttle always passes over the full breadth of the warp, of which only one portion, say one-third, is to be used, it unwinds the full length of weft thread from the bobbin, but only one-third of it is tied in the warp. In repassing the shuttle one-third more is tied, thus leaving one-third of the unemployed weft thread in the form of a loop upon the article manufactured.

"To remove this superfluous thread, the thread-catcher, which is a lever with an elastic finger, passes from behind, through the lay on each side of the reed, and pulls the thread out.

"In consequence of this partial opening of the warp the fly-shuttle could not be used, and another contrivance had to be resorted to. This consists in a carrier by which the shuttle is conveyed to the centre of the warp, where it is taken by the other carrier and passed through the warp. By these carriers a very even motion, free from all sudden jerks, is imparted to the shuttle, so that the finest silk and the loosest wool can be worked with this lay as neatly and easily as by hand, without the least danger of breaking the thread, as would happen with the fly-shuttle.

"The most difficult part of the work is performed by the *regulator or take-up motion*, the action of which is to take up the woven cloth in such a manner as to leave a straight line in front of the reed. As the cloth is woven first only on one side; then, for the whalebone pockets, where the cloth is double, evenly over the full breadth; thirdly, on the other side only; and, finally, for the full breadth at the back and front of the stay, the motion of the regulator must change accordingly. To effect this the cloth passes between two sets of rollers, the upper of which are simple pressure rollers, to be regulated by springs and set screws. The lower rollers are fluted and worked by a system of levers independent of each other. The levers are worked conjointly by the Jacquard and

lay, so that the lay gives only a movement to those levers which have been previously acted upon by the Jacquard.

"A very elastic warp tension is obtained by a peculiarly constructed lever combined with an elastic brake, so as to render the whole machine fit for any kind of work—flat or convex, plain or richly ornamented—according to the cards placed upon the Jacquard, and the material put in warp and shuttle."

CHENILLE-MAKING MACHINE.

A small machine, apparently simple in its construction, but nevertheless quite puzzling to the spectator of its operations, was exhibited by F. Martin, of Lyons, for the manufacture of chenilles. In this manufacture, by whatever process conducted, the material is continually reflexed upon itself, so that the article in the first instance presents a series of close loops which must be cut to give it finish. The machine of Mr. Martin performs the operation of weaving and cutting at the same time; and the finished chenille is turned out with a rapidity which is truly marvellous. The particular machine in operation at the Exposition produced more than two and a half yards a minute, and the quality of the product is much superior to that which was furnished by processes previously in use. The invention of this machine is not very recent, as it dates back to 1851, but it has given a large development to the manufacture. Mr. Martin, in a note to the committee, has furnished some interesting information on this subject. He states the production of chenille, in France alone, to amount at present to five or six millions of francs annually. The manufacture is also carried on in England on a very large scale. There are now in that country some thousands of machines in operation. One manufacturing establishment at Derby, near London, in operation ten years, has declared dividends to the extent of 750,000 francs. Mr. Martin adds: "I have taken no pains to make this machine known; it has made its own way from the beginning; I did not trouble myself to patent it, though I have patented more than twenty other inventions. Other mechanicians have constructed machines to accomplish the same end. Most of these machines are designed to manufacture two pieces of chenille at once; some of them more. According to the excellence of the mechanism and the capacity of the workman, these machines will produce on an average a thousand to fifteen hundred metres of chenille a day. There are workmen of exceptional ability who will make more, but rarely. For the sake of ascertaining the productive power of a machine, I have myself pushed the production up to twenty-five hundred metres; but this rate could not be permanently maintained. All my machines have been made for a single piece, for which the management is easiest and most agreeable. The one at the Exposition, under the direction of an intelligent workman, makes on an average fifteen hundred metres a day. This form of the machine is adapted to all sizes of chenilles, which is not the case with most others.

"Chenilles are now employed in a great variety of novelties—shawl fringes, embroideries, head-dresses, tissues, &c., &c. The new manufacture has entirely subverted the old, which was carried on by weaving. The product was by no means so beautiful, and the sale was comparatively trivial, not having exceeded two or three hundred thousand francs for France; and I am not aware that the manufacture had any existence elsewhere. It required a much larger capital, which was itself a serious obstacle in the way of production."

At a comparatively late period of the Exposition there appeared a rival and more recently invented machine for the same manufacture, for which patents have been taken in France, England, and our own country. This was a machine making several pieces at once, producing, as was stated, an "enormous" daily fabrication, though the amount was not given in numbers. But the special merit claimed for it by its inventor, Mr. L. Couchoud de Gournay, of Paris, was that it requires so little superintendence as to make it possible for twenty-five or thirty machines to be managed by a single woman; whereas the ordinary machines exact the exclusive attention of a skilled workman for each.

Both these machines are exceedingly ingenious, and happily illustrate the extent to which a single and apparently minor invention may develop an insignificant industry into an important branch of manufacture.

PAPER-FOLDING MACHINE.

A machine for folding printed sheets has been in use in some of the newspaper offices of our country, and perhaps continues still to be used; but no such machine, so far as the knowledge of the writer extends, has been here found available for folding book sheets, or has performed its task with a sufficiently accurate register for that purpose. In general, also, the number of folds given to the sheet has not been sufficient to serve for book forms.

In the French section of the Exposition there was constantly to be seen in operation throughout the season a very compact and efficient folding machine invented by Messrs. Frédereau and H. de Chavannes, of Paris, in which sheets requiring many folds were very rapidly and very accurately reduced to book form. The machine received the sheets from an attendant, whose duty it was to adjust them at starting to two determinate marks of reference, after which they were whirled through the machine with surprising rapidity, and turned out almost immediately neatly folded, and with an exactness of register rarely seen in the best hand work. As books usually require to be divided at least once, this machine is constructed so as to make the necessary cut, and to fold the two halves independently. A little statement of the history, the principles of construction, and the economical usefulness of the machine, printed in 32mo., and folded by the machine itself, was distributed to visitors. The inventors say in this that they were induced to undertake the construction in consequence of the steadily increasing cost of hand

work, and the difficulty of finding persons willing to submit to a labor so fatiguing and so ill-paid. There were also great inconveniences to publishers arising from the necessity of letting this work go out of their establishments to be performed by operatives in their own homes; in consequence of which they were liable to loss, injury, and delays, and were able after all, in many instances, to secure only a very ill-executed description of work. The inventors profess to have acquainted themselves with the forms of folding machines heretofore introduced into America, England, Switzerland and France, but say that none of these have been equal to any but the simplest kind of work, and none of them have been sufficiently rapid to be truly economical. In their own machine they say that the mode of presenting the sheet, the saws which divide it, and the arrangements which allow the parts to be adjusted to sheets of different sizes, are all original.

The rapidity with which the machine can be made to work depends upon the aptitude and dexterity of the operative who presents the sheets. An attendant of ordinary skill has been experimentally found capable of adjusting and presenting from one thousand to twelve hundred sheets per hour; which, completely folded in 32mo., are an equivalent to the work of ten or twelve practiced folders by hand. This is evidently a considerable economy, since the force required to drive the machine is insignificant. Moreover the experiments on which these figures are based were made in the earlier period of the history of the invention, and more recent improvements have considerably facilitated the work of presenting the sheets, so that the economy is really greater than it seems.

On the other hand, when the number of folds required is smaller, the economy is less, since the number of sheets presented will still remain the same, while hand laborers despatch more in proportion as the required number of folds diminishes. Hence, therefore, for a quarto form the machine will do only about the work of two workmen; and for a folio, only the work of one. For a single fold, therefore, there would be really no economy, but, *per contra*, no one would think of using a machine to make but a single fold.

The inventors suggest, however, that even for a single fold an advantage would be found in placing the machine in immediate connection with the printing press, and causing the sheets to be automatically presented. This for newspapers would be very feasible, but not so for books, in which case the sheets require to be dried and pressed before being folded.

Apparently this machine is destined to be better known. Admirably, however, as it certainly performs its work, it is not in all respects so complete as one or two which were exhibited in London in 1862. Both of these were from Switzerland, and one of them, the result of the successive labors of two or three inventors, Messrs. Sulzberg, Graf, and Tanner, not only folded the sheets but stitched them. The operation of

this machine is thus described by the jury of the class in that Exposition: "The sheets are put singly by a boy under the points of the machine in the same manner as in the printing machine. A knife moving up and down takes hold of the sheet lengthwise in the centre, draws it through a slit in the table and the first fold is made. The knife returns instantly and the sheet is taken by a second vertical knife, folding it at right angles to the first fold. Before the third fold is made the stitching operation commences; two needles, provided with hooks, passing through the middle of the sheet about an inch distant from each other, draw through the cotton unwound from a bobbin and cut to the required length. The sheet is then folded a third time by a knife acting at right angles with the second one, which takes hold of the sheet and pushes it between a pair of ribbed rollers, whence it passes directly to another pair of polished rollers, and remains glazed on the table. The machine works so correctly and truly that the sheets are folded and stitched with the utmost exactitude in the centre, and are so well pressed that the binder can immediately begin wrappering. It is, moreover, so constructed as to fold the largest as well as the smallest sheets; and both the stitching and the pressing apparatus, or each singly, may be detached by the loosening of a screw. It can be worked by either hand or steam, a boy being sufficient for that purpose."

In regard to the other machine of the London Exposition, the jury say: "It feeds itself without any human aid whatsoever, by means of a very ingenious air or sucking apparatus, which takes the sheets one by one from a pile under the horizontal folding knife, thus enabling it to fold 3,000 sheets per hour with the same precision as the first machine; without, however, making so perfect a register, as no points are used in laying on, and it is therefore best adapted to the folding of newspapers or other periodicals, where a perfect register is not absolutely required."

From these statements it appears that the Swiss machines possess merits not inferior to those of the French machines exhibited, while in this latter no provision is made for stitching the folded sheets. The ingenious expedient of picking up single sheets from a pile by an aspiring apparatus is becoming general in this class of industries. It is employed in a machine exposed in the French section designed for folding envelopes; and it is also used in the note-stamping machine constructed for the Bank of France, elsewhere noted in this report.

ENVELOPE-FOLDING MACHINES.

The immense increase in epistolary correspondence which has taken place since the commencement of the era of cheap postage, has led to a corresponding increase in the consumption of letter envelopes. The demand has been so great as to make the employment of machinery in the manufacture a necessity. Many envelope-folding machines have accordingly been introduced, and these were numerously represented at the Exposition. With these machines, in their ordinary forms, the public is

already familiar. Only one of those exhibited seems to possess sufficient originality or novelty to require mention here. This is said to be a British invention, although it was not exhibited in the British section. The exhibitors were Messrs. Robineau and Roumestant, of Paris.

The peculiarity of this machine is a very ingenious application of the principles of pneumatics to effect certain parts of the operation, with the advantage of a material simplification of the mechanism, and a very important increase in the rapidity of working. The pneumatic apparatus acts, in different stages of the process, both by aspiration and by insufflation. Aspiration or exhaustion is used to lift and transport the paper to the place in the machine where it is to be folded, and insufflation, or a blast produced by compression, subseqently bends over the four angles into a position to receive the pressure of the platen which folds them.

It is, of course, understood that the paper has been already cut to proper form before being introduced into the folding machine. This process of cutting is machine work also; and it presents the sheets in piles like solid blocks, all having the form of an envelope opened out flat. One of these piles or blocks is placed upon a plate or tablet in the machine, to which a periodical motion of elevation and depression is given by means of a cam and spiral springs. At each upward movement the pile meets the *aspirator*, which is a forked tube, the two branches of the fork being flattened, and perforated on the under side with numerous minute holes. The tube which forms the handle of the fork communicates by means of an India-rubber tube with the air-pump. As the pile of sheets comes in contact with the perforated tubes, the upper sheet adheres to them by the effect of the aspiration, or sucking, and when the pile falls away this upper sheet remains suspended. In consequence of the bifurcation, it is held by the parts which are subsequently to be folded over. The aspirating tubes are sustained by a carriage which now runs forward and transports the sheet to the point where the folding is to be performed.

The folding apparatus consists of an open box of metal having the size to which the envelope is to be reduced. Immediately over it is a plunger or platen of the same form as the box. So soon as the sheet is in place—and it is dropped more exactly in place than a workman could arrange it by hand without occupying a very sensible time—the plunger descends, and the sheet is pressed down into the metal box, so as to form as it were a lining to it, or a paper box of the same form; with, however, its four angular points standing upright. In the mean time, however, one or two important operations have taken place. The point which is to form the lower side of the envelope, and to fold over the two ends, is gummed, and the opposite point receives any stamp which it may be desired that the completed envelope shall bear in the place of the seal. The exhaustion in the aspirator then gives place to insufflation, the paper is released, the platen descends, the aspirator

withdraws to pick up another sheet, and the platen rises again, leaving the paper lining the metal box as above described.

In the sides and ends of the box, near the bottom, or just above the fold in the paper already made, there are perforations in a horizontal line, through which, in the present state of things, there enters a strong blast of air, which has the effect to bend all the upright sides of the paper lining inward so far that a second descent of the platen occurring at the same time completes the folding and fastening of the envelope by a single movement. The platen rises once more, the bottom of the box drops, and the envelope is thrown out.

It is of course necessary that the angles of the paper, when bent inward, should observe a certain order. The ends must bend first, the lower angle next, and the upper angle last. This invariable result is secured by the very simple expedient of admitting the blast to the several sides in this same order. The difference in the actual time of admission is indeed very small; but the smallest difference suffices for the effect.

A single machine of this description will fold twenty thousand envelopes in a day of ten hours, or about two thousand an hour. This great expedition is chiefly owing to the extreme facility with which the sheets are picked up separately by the aspirator, and the exactness with which they are put down in place, without any loss of time. No other mechanical means could be relied on to perform the first part of this work, and to do it by hands is both troublesome and slow. This same principle (aspiration) has been found advantageous in other machines for working in paper; as in the Swiss book-folding machine just mentioned; and its evident capabilities are such that we may expect to see it hereafter exemplified in various new forms.

FRICTION MATCHES.

These objects are now manufactured by machinery on a very large scale, with the advantage that the machine-made matches are neater and more uniform in appearance and better in quality than those made by hand. Matches of cylindrical form have been chiefly heretofore handmade, and the figure has been given by compression or by drawing the wood through holes in a plate in the manner of wire drawing. But this, while improving the appearance, diminishes the inflammability and renders the match more liable to fail. The hand-made cylindrical matches have been chiefly produced in Austria, from which country there has been a considerable exportation. A machine was exhibited by Messrs. Rimailho Brothers, of Paris, for manufacturing the wooden cylinders without compression. Many of the Austrian matches have been made without compression also, but still the cylinders are prepared by hand. They are cut from large planks of fine even-grained wood, by means of a large joiners' plane, carrying a series of steel tubes with sharp edges, instead of the usual planing tool. The effect of this operation is the pro-

duction of a series of long, thin splints of wood of perfectly circular section, which are afterwards cut up into short lengths as required. It has been long wished to substitute machinery for the joiners' plane in this operation, but the difficulties arising from irregularities of the timber and from other causes were very great. Messrs. Rimailho have at last successfully solved the problem in a very simple manner. They cut the blocks of wood to the exact lengths of the matches first of all, and produce the round splints from these short blocks. By these means they are less dependent upon the quality of the wood, as the cut is not materially influenced in the short length of two or three inches. The machine for doing this consists of a slide carrying a series of tubes made out of a solid piece of steel and kept sharp at their edges, and of a simple frame for holding the wood block in contact with the tool. The slide is moved forward and backward by an eccentric very rapidly, and cuts a row of matches at each stroke, each fresh row throwing those previously made out of the machine. The machine exhibited is double, consisting of two such slides fixed at opposite sides of the eccentric, which works both. The action is very rapid, the machine throwing out a small bundle of matches at each stroke, and the quality of the article produced is superior to that made by hand. Messrs. Rimailho have several such machines at work in their own factory.

Machines were also exhibited for performing the operation of dipping the matches, by means of which the work is accomplished with wonderful rapidity. One of these, the invention of Mr. G. Schmidt, of Paris, would arrange for dipping no less than six thousand matches in four minutes. The splints properly cut and prepared are received upon a horizontal plate or table grooved to the size of the matches, and are made to fall into the grooves by the action of a broad brush which is suspended above the table, and which the operator moves by means of a pedal. The effect reminds one of the arrangement of coin by similar means in the counting machines of the mint. In front of the table on which the matches thus arranged lie, is a frame placed vertically, which is designed to receive a number of layers of matches one above another. This frame presents immediately before the row of matches a narrow receiving plate or bed. By the action of a second pedal the workman causes a row of needles to advance, which push forward the matches on to this plate, and are retracted by a spring. The matches are pushed beyond the edge of the receiving plate just so far as may suffice for dipping, and their ends are kept separate by thin partitions, which are a fixed part of the machine. The frame, which has a movement up and down in guides, is then depressed sufficiently to permit another receiving plate to be laid on the last row of matches, at a proper level to receive an additional row; and this process goes on until sixty rows, each containing one hundred matches, have been piled up in the frame. The frame is then locked up by bringing down a traverse bar at the top, so as to compress the whole mass and secure it in place. The matches are thus confined

very much in the same manner as the type in a printer's chase. They are then evened at their ends like type, and are ready for dipping.

A machine for preparing wax-coated matches for dipping, invented and exhibited by Mr. Mujica, of St. Sebastian, Spain, was in some respects similar to the one just described. In this, however, the lengths are cut by the machine which arranges them, all the matches of each layer being cut simultaneously by one action of the knife. The material, which is flexible, being a cotton wick covered with wax, is placed in the machine in coils. From these coils, or bobbins, seventy-two little waxen cylinders are carried forward by the rotation of a pair of feeding rollers, and at the proper moment the knife cuts them, and the matches thus cut off rest upon a receiving plate covered with flannel. For the rest, the operation is essentially the same as that described above. The frame is depressed in this case by means of a screw, and a second plate is placed on the row of matches which has just been deposited. The frame will hold four thousand or more matches, which are secured and dipped as above described. The whole operation occupies from five to eight minutes. A single workman will be able to prepare and finish with this machine as many as four hundred thousand matches in a single day.

MATCH-BOX-MAKING MACHINE.

The immense number of friction matches annually made and sold renders it necessary to employ rapid modes of manufacturing the boxes required to contain them. An ingenious machine designed for this purpose was exhibited by Mr. L. Poirier, of Paris. The boxes are made of pasteboard, which is cut into pieces each of suitable size to make the body or the top of a box. These pieces are rectangular in form, but are rounded at the angles. They are introduced by hand one by one into the machine, and are instantly forced by a plunger into a box-shaped matrix, or socket, where they receive at one movement the form desired. In this operation the corners, in which the material is in excess, are folded over on the sides, and an energetic pressure is exerted on the folds by means of four cams; in consequence of which these folds become compacted into one mass with the sides of the box. The union is perhaps not as perfect as it might be made by the application of a little paste to the angle before compression, but it is apparently quite firm, and answers certainly perfectly well the simple purpose intended. Nearly three thousand boxes are manufactured per hour by one of these machines. The number might perhaps be increased by the addition of a contrivance for placing the cards in the machine without exacting the constant attention of a workman.

SUGAR-CUTTING MACHINE.

A simple machine for cutting up white sugar into little cubes for use was exhibited in the Belgian section by Mr. W. Devisseber. The sugar is first prepared for the machine by means of circular saws, which reduce

it to the form of long, square sticks. These are dropped into upright grooves in the machine, of which there are a number side by side, and of which the bottoms are movable. These movable bottoms are formed of a pair of plates of metal which meet in the middle beneath the grooves, and when closed arrest the descent of the sugar. A little above these plates, at a height suitable for making the cut, are placed a pair of knife edges which move inward toward each other and divide all the columns of sugar simultaneously. As the knife edges close, the supporting plates open, and allow the pieces which have been cut off to drop. This reciprocating action takes place rapidly, and all that is necessary to keep up the process is to supply the columns of sugar from above.

BOTTLE-WASHING MACHINE.

A machine for expeditiously washing bottles was exhibited by Mr. W. E. Hickling, of Grantham, England, which seems to deserve the attention of persons in the wine trade and of bottlers generally. Machines of this description are extensively used in the principal British bottling houses. The design of the machine is to give a rapid agitation to a large number of bottles at once. The immediate cleansing is accomplished in the same manner as in hand washing, that is, by the introduction of solid substances along with water into the interior of the bottles. The machine therefore performs very thoroughly, and upon several bottles at a time, an operation which is performed less perfectly and in longer time by hand upon a single one. The solid substance introduced is shot, with which the bottles are about one-third filled. They are placed in the machine in a horizontal position between base plates coated with India-rubber, and India-rubber stoppers. Eight bottles are arranged in a circle around a horizontal spindle, and eight more form a second group upon the same spindle. A rapid reciprocating motion is then given to this spindle by machinery, and in the meantime the spindle turns upon its axis, so as to bring every part of each bottle successively into the lowest position. Sixteen bottles are thus washed at once, and one machine driven by steam will wash from forty to forty-five gross of bottles per day. The bottles are placed in the machine and removed very expeditiously. Different sizes of the machine are constructed for different kinds of work. They are adapted to the washing of vials on the one hand not larger than of two ounce capacity, and for cleansing jars, casks and barrels on the other of any magnitude.

MACHINE FOR CORKING BOTTLES.

To introduce a cork into a bottle mouth considerably less in diameter than itself, is, by the methods ordinarily practiced, a troublesome operation, but it is one which must be performed if it is desired effectually to prevent the escape of the gases of effervescent liquids. A machine for expeditiously accomplishing this object was exhibited by Mr. Chalopin,

of Paris. In whatever mode the work is done it is necessary, of course, that the cork should be in the first place thoroughly soaked in hot water. It becomes then so soft as to be easily compressed into any shape, and in changing its figure it is not in danger of being broken.

Mr. Chalopin's machine presents at the top a funnel-shaped socket, opening through a metallic cross-bar. The orifice of the funnel at the bottom is just equal to or something less than the size of the bottle mouth. The bottle is placed beneath, presenting its mouth opposite this orifice, and a pedal, or sliding wedge beneath the bottom of it, holds it firmly in place. The softened cork is dropped into the funnel above, and a piston worked by a lever descending upon it drives it by one or two efforts completely into the bottle, when it may be secured in the usual way. It is unimportant to the success of the operation which end of the cork goes first. The sloping sides of the conical funnel reduce its diameter with the utmost facility, and the whole operation is complete in two or three seconds.

II. MISCELLANEOUS INVENTIONS.

ELECTRICAL DETECTORS, APPLIED TO POWER LOOMS.

One of the most useful additions which has been made within the past few years to the machinery for weaving, has been a system of electrical detectors designed to give instant notice whenever a thread breaks, either in the warp or the woof, whenever a serious defect occurs in the fabric, or when any part of the machinery itself becomes deranged. On the occurrence of any of these accidents, the motion of the loom is instantaneously arrested, and the attention of the superintendent is called by the sound of a bell. The following notice of these ingenious contrivances is derived from the London Engineering:

"Applications of this nature, contrived by the joint invention of M. Radiguet, a mechanical engineer, and M. Lecène, manufacturer of textile fabrics, are exhibited in the Paris Exhibition, applied to knitting-looms; and to show that the principle is applicable to machines already in existence, they have been attached in the present instance to an ordinary loom not made expressly for the purpose. It is now some twenty years past since the manufacturers of textile fabrics have seen the necessity for some means of preventing the serious accidents which are at any moment liable to occur by the breaking of threads, &c., especially in the manufacture of the finer articles, and this the present arrangement effectually succeeds in doing by immediately stopping the machine on the occurrence of the most trifling accident. This is accomplished by so arranging the machine that, on the breaking of a single thread, the emptying of a bobbin, the accidental bending of a needle, or on holes being caused in the work by the knotting or thinning out of a thread, an electric circuit is completed, which, passing through an electro-magnet, causes it to attract an armature, and so releases a lever, which, actuated by a strong spring,

withdraws a clutch through which motion is communicated to the loom, and the machine is instantly stopped. It will thus be seen that, even in the manufacture of the most delicate textiles, one person would be enabled to superintend several looms. The following explanations will render the mode in which this may be accomplished perfectly intelligible, and as the principle may equally well be applied to any sort of machine, we have not thought it necessary to further illustrate by a wood-cut its mode of application to any one machine.

"One pole of an electric battery is connected with the frame work of the loom, while the opposite pole is in communication with all the various working parts of the machine which are in close contact with the textiles, and which are all carefully insulated from the frame of the machine by ivory, horn, caoutchouc, or other non-conducting material; and in some instances insulation between the two parts is maintained solely by the threads of the manufacture. An electro-magnet is connected with the frame of the machine, and its armature, when not attracted, supports one end of a lever; on the other end of this lever is a hook by which another lever connected with the clutch on the driving-shaft is held back, and so long as it remains in this position the machine is kept in motion. As soon as anything goes wrong with the machine or with the work, a circuit is made, the armature supporting the holding-back lever is withdrawn by its being attracted by the electro-magnet, the spring behind the clutch lever causes the clutch to be withdrawn, and the loom is stopped.

"It has been stated that one pole of the battery is connected with all the pieces of the machine immediately connected with the threads or the manufactured texture, and that these pieces are insulated from the body of the loom; some of these pieces are withheld from connection with the other pole by the threads passing from the bobbins to the needles, and are called 'break-threads,' for so soon as a single thread breaks, or a bobbin becomes exhausted, they fall by their own weight upon a bar in electric connection with the opposite pole, and so complete the circuit and stop the machine. Small metallic disks rolling on the material as it is made, and pressing it against the side of the machine frame, from which they are only insulated by the threads of the manufactured material, instantly detect any flaw caused by defects in the thread, which admit of their coming in contact with the machine frame itself, when the machine is, of course, instantly stopped. Again, plates are put under the needles themselves, at such a distance that, in the event of one of them becoming broken or bent to such an extent as to affect the work, it would be brought into contact with it on passing, and stop the machine."

This notice overlooks what, to the visitor, appeared to be the most curious part of the contrivance, and which had very much the seeming of a veritable intelligence. This was the attachment employed to detect the failure or rupture of the yarn in the shuttle. The contrivance here

referred to consists of a delicate lever at the side of the loom, between the web and the apparatus for throwing the shuttle, which descends the moment the shuttle reaches the end of its course, with a motion like that of a finger feeling for some object of interest. If the yarn is unbroken, it bridges of course the space between the web and the shuttle, and arrests the finger, which thereupon, as if contented, retires; but if there is no yarn, or if the yarn, being broken, is slack, the finger descends further, and the consequence is an electric contact, which causes an instantaneous disconnection of the motor, and a violent ringing of the bell, while the loom is stopped before time enough has passed to allow the shuttle to be thrown again. The movement of this little sensitive finger was watched with amused interest by crowds every day. It furnished one of the most striking illustrations of the extent to which force has been subdued to be the submissive slave of man, putting forth and withdrawing its energies in obedience to the lightest touch; and that touch not even applied by the living man himself, but by a delicate and unconscious apparatus to which he seems to have transferred a part of his own consciousness.

In connection with the alarm bell, it is proposed by the inventors to add a visible indicator which shall point out to the attendant the particular place where the rupture or derangement has occurred. This, it will be obvious, will be a material advantage in respect to economy of time; for when there are so many little sentinels on the watch, it will not be easy at once to discover, without such assistance, which it is which has given the alarm.

The following relates to the application of similar detectors to stocking-looms, or more generally to machines for knitting of every description, many of these being employed in the manufacture of under-garments for the body, of knitted scarfs, shawls, &c. Several machines of this class were exhibited by Messrs. Berthelot & Co., of Troyes, among which both the circular and the rectilinear forms were represented. It was claimed for these as a main point of superiority, "that by the substitution of a segment of a large circle for the small wheel which governs the action of the needles, the thread is exposed to a less rapid change of direction, in consequence of which it is less liable to fracture, especially in the case of fine yarns. One of the circular looms on exhibition was weaving No. 34 yarn, and the fabric produced was of remarkable fineness and flexibility. In two of the circular loom of these makers, arrangements are introduced whereby the breaking of a thread will at once notify the fact to the attendant, in the one case by ringing an electrical bell, in the other by stopping the machine.

"In the electrical arrangement, each thread proceeding from its bobbin to the machine passes through an eye at the end of a very slight wire lever, and the thread sustains the lever in the prescribed position so long as it is unbroken; but if the thread breaks, the slender lever falls down

upon another metallic surface whereby electrical contact is established, and a suitable bell is rung.

"In the other machine the same effect is produced by mechanical means. A slender lever is sustained in its position by the thread as before, and this lever, in its turn, sustains a strong piece of flat iron, which, when let down, encounters projecting pins on the top of the machine, whereby a clutch situated on the driving-shaft is thrown out of gear, and the machine, of course, stopped.

"In the flat machine there is a self-acting arrangement for reducing the width of the fabric as the machine proceeds. A lever, carrying eight points, or needles, arranged horizontally, facing the eight hooks at the extreme end of the loom, is so governed by suitable mechanism, that after a certain number of loops have been woven, the points penetrate the loops on the extreme needles, withdraw them and transfer them to the needles immediately adjoining, whereby these last needles have each two loops instead of one, and the width of the fabric is reduced correspondingly. These occasional transfers are accomplished by the aid of a wheel rotating beneath the machine, and armed at intervals with suitable projections. This wheel is advanced a tooth for each stroke that the loom makes, and it is only after a certain number of teeth have thus been passed that one of the projections comes into contact with a lever communicating with the transferring points, and imparts a suitable motion to it. This arrangement is not new; but the use of a segmental piece of steel, which raises the parts usually only sustained by small spiral springs, is new, whereby the fracture of those parts is prevented, even should any of the springs accidentally break.

"By the use of these machines the exhibitor alleged that the process of manufacture is made considerably more rapid, as the machine may be driven at a greater speed from the less strain which is put upon the threads. In many of the circular stocking-looms exhibited there was an arrangement for altering the diameter of the woven pipe.

"Radiguet and Lecène, of Paris, exhibited several circular stocking-frames, in which by the aid of electricity the machine is stopped when a thread breaks, a lever in such event establishing electrical contact, and rendering magnetic a piece of iron which withdraws a detent and stops the machine. The machine is also stopped should a hole occur in the web. A small wheel revolves inside, and another outside the web, immediately beneath the knitting plane; conduction from one of these wheels to the other is prevented by the intervening web, unless a hole occurs, when contact immediately takes place between these wheels, and the machine is stopped. A similar result ensues if a stitch is dropped, as in such an event the needle, by falling below the knitting plane, will, in its rotation, come into contact with a brass plate placed close below the needle-frame, and as both needle and plate form a part of an electrical circuit, a bell will be rung."

MACHINES FOR DRYING CLOTHS.

A machine was exhibited by Mr. Tulpin, of Paris, for drying cloths, yarns, or other similar articles, by means of centrifugal force. In this there is nothing new in principle, such machines having been long in use for certain purposes, especially in the refining of sugar.

A machine for steam drying, by the same exhibitor, presents, however, sufficient originality to merit notice. In the steam drying of cloth in the piece, a cylindrical drum has been usually employed, the cloth passing round the drum while the steam is admitted to the interior. This construction imposes a limit to the dimensions which can be safely employed, unless the pressure of the steam is kept low. It limits, therefore, also the degree of elevation of temperature. On both these accounts the efficiency of the machine, or the rapidity of its action, is too moderate to make it eminently economical.

Mr. Tulpin's improvement is to employ an annular instead of a cylindrical steam chamber. This annulus is constructed of two concentric cylinders, which form a closed cavity, and constitute the circumference of a wheel more than twelve feet in diameter. Around the circumference of this wheel, which turns slowly upon a horizontal axis, the cloth is carried, being kept in position by means of two endless chains, having tenter hooks attached. The cloth passes round nearly the entire circumference, being carried off on the same side at which it was introduced; and as the velocity of motion at the circumference is but about six inches per second, it passes off pretty thoroughly dried.

The construction permits the steam chamber to be made very secure against accident, and yet to present an exterior of quite thin metal, facilitating greatly the transmission of heat. The necessary strength is obtained by means of numerous interior stays connecting the two cylindrical surfaces. The steam is admitted through the axis, passing up the spokes. The pressure is carried as high as five atmospheres, or to 300° F, and upward. For the water of condensation a separate passage is provided. It is returned to the axis and discharged by a suitable valve. In order that this may take place it is necessary that the annular steam space should be divided into a number of partial steam chambers. The water which condenses in any one of these is necessarily carried to the top of the wheel in the course of the revolution, and thus returns to the axis by its own gravity. The fact of this subdivision of the circumference of the wheel renders it practicable to take the whole machine to pieces and pack it conveniently for transportation without any disturbance of the riveted joints. This is an advantage not only when there is question of conveying the machine to a distance, but also when it is desired to introduce it into an apartment having doors of only ordinary dimensions.

It is asserted that the use of this machine is attended with a large economy of fuel as well as of time. This economy is stated by the in-

ventor at not less than thirty per cent. as compared with the cost of steam-drying in the usual methods.

SAFETY BRAKES FOR RAIL-CARS.

Whatever tends to diminish the number or reduce the danger of accidents by railroad is of general interest to the public. There can be no doubt that many of the most calamitous of the disasters which have occurred within the past twenty years upon these great highways have been owing to the impossibility of promptly arresting the motion of a train after the existence of a danger had been discovered by the engine-driver. On European railways the passenger cars are not provided with brakes. In their construction, in fact, no room is left for a brakeman to occupy, and therefore the only means which exists for stopping a long train is a brake or two attached to luggage or freight vans. In our own country every car has its brake, and when all the brakemen are at their posts and operate instantly, it is possible to bring a train to rest within a very short distance. It is said that a train running at the rate of forty miles an hour has been stopped in this manner in three hundred and seventy-five feet. In point of fact, however, the brakemen are not constantly at their posts. Whenever the train approaches a regular stopping-place they will usually be found there; but those are not the times at which dangers are most to be apprehended. It is at points distant from stations that broken rails, fallen rocks, landslides, or trains running by mistake or without authority in the opposite direction, and other analogous unforeseen causes of disaster, are liable to be encountered. In such a case it is usually the engine-driver who first recognizes the danger. He may signal for the brakes and reverse his steam; but for a number of seconds the train will continue to advance with very little check to its velocity, and before the resistance can be effectually applied it is often too late to be of service.

CREAMER'S SAFETY BRAKE.—Two inventions appeared in the Exposition, designed to provide for emergencies of this description. Both of them are in the nature of automatic and instantaneous brakes to be applied simultaneously to all the wheels of all the cars. One of these inventions is American, and was exhibited by Mr. W. G. Creamer, of New York. It has been already introduced upon several railroads in this country, and experiments have been made with it in England.

The construction and operation of Mr. Creamer's brakes will be understood from the statement that when it is employed the machinery of the system in common use remains unaltered, but that there is added to it a reserved power in the form of a closely wound and powerful spiral spring, which may be set free by the pulling of a trigger, and which when free is a substitute for the force of the brakeman. The manner in which human power is applied to railway brakes is familiar to all who have travelled upon American roads. A chain connected with the levers which immediately apply the force to the wheels, is wound round a vertical spindle,

which is turned by hand by means of a horizontal wheel at the top of the spindle. The tension secured is maintained by means of a catch, or click, which the brakeman can throw in or out of a ratchet wheel with his foot. Mr. Creamer's spring surrounds this spindle, and is so constructed as to admit of being wound powerfully up, (so as to be under a tension of not less than twelve hundred pounds weight,) and yet to leave the spindle free to be operated on ordinary occasions by the brakeman as usual. But should a necessity arise for a sudden arrest of the motion of the train, the engine-driver, by a single movement, may instantaneously release all these powerful springs to act at once upon the several brakes, and the train, even when moving with the high velocity of forty miles an hour, will stop still in from five to ten seconds.

The brakes may be put on not only by the engine-driver, but by the conductor, in whatever car he may happen to be, or even by a passenger, since the bell-cord which passes from end to end of the train is connected with the triggers, and they may all be sprung by pulling it. It consequently follows that in case the coupling of the train should give way at any point, the brakes would all be automatically sprung, and both parts of the train would immediately stop.

ACHARD'S ELECTRIC BRAKE.—The other form of safety brake above mentioned, exhibited by Mr. A. Achard, of Paris, is operated by the power of electro-magnetism.

Mr. Achard supplies each carriage in the train, to the wheels of which his brake is applied, with a galvanic battery of six Daniell cells, which he has improved for this purpose. He connects these batteries with each other and with the engine foot-plate, by means of four wires passing through the whole length of the train, and properly insulated by a coating of India-rubber or gutta-percha. By means of these electric wires the inventor is enabled to create two distinct electric currents, either of which may be closed or broken by altering the position of a handle placed before the engine-driver.

In order to explain the manner in which the magnetic power may be brought into action in applying the brakes, it must be stated that there is fixed in the frame of each car carrying a brake, a transverse arbor or shaft extending from side to side, a little in front of and above the forward axle, upon one end of which is fixed a strong ratchet wheel. A lever pivoted at a point behind the axle and lying on the axle (when the apparatus is working) carries at its extremity a click which falls into the teeth of the ratchet. The axle has a cam at the point where the lever crosses it, and this cam at every revolution of the wheel lifts the lever sufficiently to advance the ratchet wheel one tooth, when a guard-click prevents it from turning backward. The lever is kept in contact with the axle and its cam by its own weight with the aid of a spring. In the middle of the arbor carrying the ratchet is a powerful electro-magnet, firmly attached to the arbor and concentric with it. Upon the two parts into which the arbor is thus divided by the magnet there are two loose bar-

rels or drums, terminating toward the electro-magnet in circular soft-iron armatures. When the magnet is excited, these armatures are fixed by its powerful attraction, so that they and their barrels turn with it. To each one of these barrels is attached a chain, which, when the barrels are made to turn, is wound upon it, and through which the levers are operated which apply the brakes to the wheels.

From this brief account it will be seen that when the battery circuit which is employed to excite the magnets, is broken, the ratchet with its arbor may turn freely without winding up the chains, and therefore without affecting the brakes. But the moment the current is established the magnet fixes the barrels and the brake immediately begins to act.

The power, therefore, which applies the brakes is actually the inertia of the train itself. The function which the electricity fulfils is only that of making a connection between the power and the work to be done. At every revolution of the wheels the pressure of the brakes on their circumferences will be increased, until the point of tension is reached at which the armatures begin to slip on the magnet; after which the resistance will remain constant. The magnitude of this maximum resistance will depend on the power of the magnet.

As it would not be advisable to allow the ratchet lever to rest on the axle, and to keep the shaft carrying the magnet constantly revolving when the brakes are not required, a second set of magnets is introduced, of which the use is to keep the ratchet levers suspended above the working position sufficiently high to clear the cams. These magnets are fixed in position, and the battery-circuit which actuates them is kept constantly closed, except when the brakes are applied. Then a single movement of the handle before the engine-driver breaks the circuit of the fixed magnets and closes that of the movable magnets simultaneously. The ratchet levers accordingly all fall immediately into their working position, and the brakes begin at once to operate. At the same time, also, a toothed wheel, on the same arbor as the ratchet wheel, acts upon the apparatus of an alarm, and causes a bell to be struck in the carriage.

Besides the handle by means of which the engine-driver puts the brakes into operation, each carriage is furnished with one which enables any passenger to do the same thing at pleasure. As a guard against the abuse of this power on the part of passengers, it is proposed to connect with the apparatus an indicator, which will show in which carriage or compartment the interruption originated.

If, by any accident, the cars of a train become uncoupled, the wires are of course broken and the electric brakes become unavailable. But the ordinary brakes may in that case be applied, and these brakes continue to be attached to cars fitted up with Mr. Achard's improvements. Of course, from what has been said, it will be understood that, in this supposed case of danger, the alarm bells will necessarily begin to ring, so that the brakemen will be called to attend to their duty.

Moreover, since each carriage is provided with its separate battery, it would seem to require no great addition to the complication of the apparatus, to provide a separate circuit enabling each, in an emergency like that above mentioned, to work its own brake independently.

This invention has been very favorably regarded by engineers and men of science whose attention has been drawn to it. The Academy of Sciences of France, who have a fund at their disposal for awarding prizes to inventors of useful contrivances for lessening the dangers and injuries to life or limb liable to occur in the pursuit of arts and manufactures, have conferred upon the inventor a prize of two thousand five hundred francs. Trials of the apparatus were made on the Chemin de Fer de l'Est, in France, where it was applied to the express trains running between Paris and Strasburg, and on the Belgian State railway. The inventor laid before the Academy very favorable reports from the engineers of these lines, and Mr. Combes, the well-known Professor of Mechanics at the *École des Mines*, in Paris, drew up a complete report upon the action of the electric brake, in the name of a scientific committee, upon whose proposition the above-named prize was awarded.

MECHANICAL BROOM.

A cylindrical broom designed for street sweeping was exhibited at the Exposition, by the inventor, Mr. Tailfer, of Paris. This machine has been adopted in the municipal service of Paris, and is in use in other cities of France. It is simple in construction, and upon well paved streets is very effective in operation. The broom is attached to the rear of a two-wheeled vehicle, by means of a framework, which is so hinged to the axle of the vehicle as to enable the conductor upon the box in front to raise it out of contact with the pavement, or to depress it for service at pleasure. The lever by which this is effected may be secured at the lowest point, so as to maintain the broom permantly raised while proceeding to the place where the work is to be done, or when returning, after the labor of the day is over.

Upon one of the wheels of the vehicle is fixed a conical gear wheel, which drives a pinion running on an axis inclined about twenty degrees to the axis of the vehicle; and this axis is connected with the axis of the broom by a chain working in a pair of rag wheels. The axis of the broom itself is inclined so as to be parallel to the axis of the pinion just mentioned, and therefore oblique to the direction of movement. When the broom is applied to the pavement the rag chain gives it a rotation opposite to that of the wheels of the vehicle; and the dust or mud of the street is swept on before it and turned aside so as to form a continuous heap parallel to the axis of the road.

The broom is armed with stout splints, and is sixty centimetres (two feet) in diameter. In length it is about 1.8 metres—say six feet. It leaves a track cleanly swept behind it of nearly this breadth. But as the heap of dust thus thrown up is moved still further on by a second broom

following the first, or by a second operation of the same broom, it is necessary for security that the two tracks should overlap each other; and hence in calculating the amount of daily service of such a machine, its effective track is taken at 1.5 metre. The dust and filth of the street having been, by successive courses of the broom, driven up to the curbstone, or, by operating on both sides, to a single continuous heap in the middle, it is removed by scavengers' carts as usual. Observations on the actual performance of these machines in the streets of Paris show that a single mechanical broom performs the work of twelve men. The total cost of a machine complete is two thousand francs, the cost of the broom alone eighty francs. The broom, if in constant use, will require renewal about once a month.

POOLEY'S AUTOMATIC GRAIN WEIGHER.

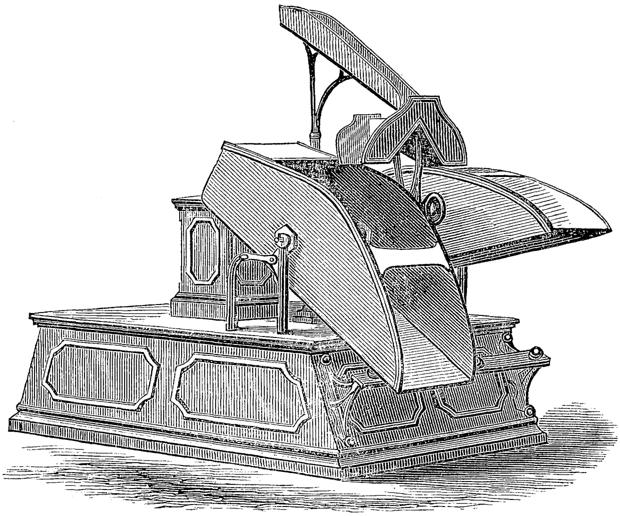
An apparatus which attracted a great deal of attention of American visitors to the Exposition, particularly of gentlemen from our agricultural districts, was a balance exhibited by Henry Pooley & Son, of Liverpool, for weighing grain, and at the same time recording the weight of the grain which has been weighed. This balance, called by the inventors the Automatic Grain Weigher, is self-acting throughout. The only force employed in the several acts of loading, weighing, discharging, and recording, is the weight of the commodity in process of being weighed. The results of any given period of work are exhibited upon the register.

To describe the mode of action by this novel machine more in detail: the grain is introduced to the machine from the depot in any manner by which a continuous supply may be conveniently delivered into the feeder; then, when the first scale has received the principal part of its load, that scale falls through a portion of its descent, and in falling lifts a proportional weight equal to the partial load then in the scale, and at the same moment moves the feeder partly towards the second scale, which then begins to be filled while the first scale is receiving slowly the finishing part of its load. When the loading of the first scale is complete that scale falls through the remaining part of its descent, and in falling releases the catch that till then had held it in its position, whereupon the loaded scale immediately tilts and simultaneously shifts the full stream of grain over to the second scale and moves the register figure. The operation thus described proceeds from scale to scale alternately as long as the supply of grain is continued. The flow of grain is never cut off or interrupted during the discharge of the scales.

What makes this invention specially interesting is the ingenuity with which a very severe accuracy in the weight of each charge is secured without any consequent loss of time. In ordinary weighing, if great exactness is aimed at, the last additions are made slowly; and this, in fact, is always necessary if one would avoid inevitable overcharge. Accordingly, as much time is spent in adding the last few grains, or the last few ounces, as the case may be, as it had required to introduce the

great bulk of the load previously. But by employing two balances side by side, with a bridge, or doubly inclined shoot, between them, the inventors have made it possible to keep up a steady flow from the source, and still to finish off each load by so gently growing an increase that it is impossible an error should occur of any sensible amount; while in the mean time the nearly empty scale receives the main stream and rapidly fills. This balance cannot fail to make its way among our western farmers, and among the large class of our citizens who are engaged in the transportation of grain.

Fig. 79.



Pooley & Sons' Automatic Grain Weigher.

The figure will be understood without requiring particular description. The parts important to note are the two scale pans, of which the one on the right is in the position to receive, and the one on the left in the position to discharge its load; the doubly inclined shoot or bridge extending across above the scales, and the supply shoot appearing above the whole. This supply shoot is sustained by a branched iron support, which is single at the base, and which forms a vertical axis around which the supply shoot has the slight lateral movements above described, which change the manner of delivery of the grain.

It is obvious that this balance is applicable to many purposes in which accurate and continuous weighing is necessary, as well as to the weighing of grain.

UNIVERSAL EVAPORATOR.

Under this name Mr. Chenailler, of Paris, exhibited an apparatus for accelerating the evaporation of liquids at temperatures below the boiling point, which seems to be capable of useful application in many industries requiring a rapid concentration of dilute solutions without urging the temperature. Such is especially the case in the manufacture of sugar; and accordingly it is stated that this apparatus has been extensively introduced, not only in the beet-sugar factories of France, but also among the planters of cane in the French colonies. The apparatus consists of a number of hollow disks, of lenticular figure, arranged upon a common

axis, and dipping into the liquid to be evaporated. These disks, or lenses, are constructed of thin metal, and are all in communication with each other through the common axis, which is likewise hollow. The whole system is kept in slow rotary motion by some convenient moving power, and each disk carries up with it, adhering to its surface, a thin film of the liquid. As evaporation when it takes place without ebullition goes on with a rapidity proportional to the surface exposed, (the temperature being supposed constant,) it is manifest that the arrangements here described will increase the amount evaporated in a given time to a degree dependent on the number of the disks. The disks exposed were about a metre in diameter, and were ten in number in each set. In addition to the disks, one of the sets was provided with a series of longitudinal tubes extending parallel to the axis from end to end of the system, around the whole circumference.

These also communicated, within, with the common interior of all the disks. The object of this communication is to allow the temperature to be raised, if desired, by the admission of steam, to which access is given through the hollow axis.

This evaporator may be used in connection with a vacuum apparatus, as well as in the free air. Mr. Chenailler exhibited the arrangement designed for this purpose. Within a vacuum chamber of the ordinary description, three of the evaporating disks are mounted on an axis, which, passing through a packing, admit of being operated from without. For the purpose of permitting an inspection of the process, sight-holes are provided, protected by a strong glazing.

In the concentration of solutions which will bear a high temperature, the inventor claims a very large economy for this contrivance—not less indeed than seventy-five or eighty per cent. "If," he says, "we take as the basis of reckoning, the fact, theoretically established, that one kilogram of combustible should evaporate five litres (kilograms) of water, I can affirm that with only the same quantity of combustible and the use of my apparatus, no less than eighteen or twenty litres can be evaporated." And this, in establishments which employ steam as a motive power, may be accomplished without any expense at all, if only a portion of the exhaust steam, which would otherwise be wholly lost, be made available for the purpose.

By the aid of the ten-lens apparatus, without the extra tubes, this exhaust steam can be made to evaporate twelve thousand litres (four hundred and forty-four cubic feet, and more than threee thousand gallons) in twenty-four hours; and with the other form, the quantity evaporated in the same time becomes as great as eighteen or twenty thousand litres. It is claimed, also, that when the liquids become dense, a very great advantage arises from the mechanical division and agitation produced by the rotation of the disks.

In the preparation of sugar this mode of evaporation is asserted to be productive of very sensible improvement in quality. The sugar is

said to be whiter than that obtained by the usual methods, to be larger in grain, and to refine with greater facility. The product, therefore, commands a higher price.

It is also stated as a fact, in the description of the apparatus furnished by the inventor, that a number of houses which have acquired a just celebrity for the beauty and excellence of their sugars since the introduction of these machines, introduced them into their establishments originally only after having made trial by way of experiment of a single one of these evaporators, while continuing for the time being their previous methods; but that those trials were so entirely convincing as to lead them to sacrifice all their old material and to replace it with these machines exclusively.

In some of the notices of this apparatus which have appeared in industrial journals, it is stated that the invention is an old one revived. Whether new or old, however, it is believed not to have been heretofore used in the United States.

AUBIN'S IMPROVED MILLSTONES.

Mr. I. Aubin, of Paris, exhibited in Class 50 a form of millstone of his invention, which seems to possess some advantages to recommend it. A mill was also at the same time in operation to illustrate these advantages. This millstone (the lower stone) is cut through in the direction of the radius with several elongated or sectoral openings, which are covered with finely woven wire gauze. The effect of this is to permit the escape of such portion of the flour as has been sufficiently ground, while the coarser particles are passed on for further grinding, and the bran is carried to the edge before being discharged. The bran is thus pretty effectually separated from the flour during the process of grinding, and the bulk of the flour will be found in the receptacle immediately beneath the stone; while the bran with very little flour will accumulate in another annular receiver at the circumference. This does not of course supersede the necssity of bolting entirely, in case a very fine article of flour is required; but it renders bolting unnecessary for ordinary qualities, and it reduces very much the work of the bolts. It is Mr. Aubin's belief that flour is injured when the grinding is unnecessarily protracted, in consequence of the heat developed; and he asserts that with the use of his stones there is obtained both a larger weight and a better quality of flour from a given quantity and description of wheat than the ordinary mills will furnish. He claims also an additional gain from the diminution of the driving force consumed, in consequence of the relief to the mill offered by the escape of the flour as soon as ground. This improvement is one which apparently deserves to be carefully examined.

DOOR OPENING BOTH WAYS.

Among the inventions of minor importance exhibited, was a door provided with a simple mechanical contrivance for changing the hinge

from one side to the other at pleasure. In order to effect the change it is only necessary to push a knob, having the form of an ordinary door knob, a few inches to the right or to the left. The knob is placed in the middle of the door, and is connected by means of rods or bars with a pair of bolts at each edge or margin of the door, one at the bottom and the other at the top, which move vertically. The motion of the knob which forces one pair of these bolts outward draws the other pair inward. If, for instance, the bolts on the right side of the door are forced out, they enter into metal sockets in the door frame and form a hinge on that side, while at the same time the pair on the left are withdrawn from a similar pair of sockets, leaving that side of the door free. The same movement brings into place on the free side, a catch fastening of the ordinary kind, which is commanded by the same knob which has operated the change. This contrivance, which would be of little use in the case of large apartments, may, nevertheless, be very convenient where space is limited and passages are narrow. For closets, clothes-presses, and for doors in corners of rooms, or in places where several open near together, there may often be a considerable advantage in temporarily changing the hinge from one side to the other. The inventor is Mr. H. C. Lacy, of Brighton, England.

DOOR WITH MECHANICAL PLINTH.

Another invention which may be classed with the last mentioned in regard to importance, is a door with a movable plinth, designed to exclude draughts, exhibited by Messrs. Jaccoux & Son, of Paris. This plinth is so contrived that when the door closes it shuts down closely upon the floor, and effectually prevents the admission of air. But when the door is opened, a system of springs immediately raises the plinth, so as to prevent friction, and keeps it raised until the door is again closed. The falling of the plinth is caused by a pin projecting from it, which strikes a metal plate on the door frame. Of course, when the idea is once conceived, many forms of mechanism may easily be contrived for accomplishing the object desired.

CHAPTER IX.

PROCESSES AND PRODUCTS.

THE PRODUCTION OF STEEL—PUDDLED STEEL—PRODUCTION OF LARGE MASSES BY KRUPP—BESSEMER STEEL—FERRO-MANGANESE—BESSEMER-STEEL BRIDGE—BERARD'S PROCESS—STEEL DIRECT FROM THE ORE BY SIEMENS'S PROCESS—ARTIFICIAL STONE—BÉTON-COIGNET—ITS APPLICATIONS—RANSOME ARTIFICIAL STONE—ARTIFICIAL FUEL—AGGLOMERATED COAL—MATERIAL AND MANUFACTURE OF PAPER—WOOD PULP—CHEMICAL TREATMENT—EXTRACTION OF OILS BY SULPHIDE OF CARBON—REMOVAL OF OIL FROM WOOL—ROBERT'S DIFFUSION PROCESS FOR SUGAR—ENAMELLING AND BRONZING—PLEISCHL'S ENAMELS—GLAZE FOR CASKS—TUCKER'S BRONZED IRON—PA KESINE.

I.—THE PRODUCTION OF STEEL.

Although it has been committed to other and abler hands to report upon the machinery and processes of mining and metallurgy which were illustrated in the Exposition, yet it cannot be out of place, in a review of industrial progress like what is here proposed, to mention, at least historically, the signal revolution which has taken place within the last twenty years in a department of production so important as the manufacture of steel. It is only within a period thus limited that a mass of this valuable material could be produced, by any known process, exceeding in weight two or three hundred pounds. Nothing could better illustrate the magnitude of the improvements which later years have brought than the fact that there is now hardly a limit assignable to the weight of the masses which are quite within the resources of the metallurgist. The most ponderous structures and the most powerful machines may now be provided, in all their parts exposed to the action of great forces of compression, extension, or strain, with the material possessing the greatest known power of resistance, and at a moderate expense. And the statement of the fact that this may now be done cheaply does not by any means tell the whole story of the progress which has been made, since only a few years ago the thing could not have been done at any price at all.

A review of recent inventions would be singularly deficient in completeness which should omit to mention the most important of them all; and such, in view of their far-reaching consequences, must be regarded those which have recently so thoroughly revolutionized the manufacture of steel. In what follows, the object has not been to describe the processes themselves, whether new or old, which are employed in this great

department of industry, but merely to give such an outline of the history of progress as to convey an idea of the greatness of the recent changes.

ORIGIN AND PROGRESS OF THE MANUFACTURE.

The manufacture of steel is one of those industries of which the origin is too remote to be distinctly marked in history, yet which for many centuries continued to be among the least progressive of all. The material was originally produced, and is still in small quantities produced, directly from the ore; but for this purpose only a peculiar kind of manganiferous iron is available, which is not found except in limited quantities, and in particular localities. The manufacture of natural steel is at present confined chiefly to the island of Corsica, and to Catalonia, in Spain.

Most of the steel employed for the general purposes of industry, was for a long time produced by a process called cementation, the immediate product being what is well known as bar steel, or blistered steel. This is prepared by exposing bars of malleable iron in contact with charcoal in close vessels of refractory materials, for a considerable time, to a high temperature. The duration of the operation varies with the cross section of the bars to be cemented, but it always continues for several days, and after its completion a still longer time must be allowed for the cooling of the mass before it is withdrawn from the furnace. Ten or twenty tons of iron may be cemented at once in a single furnace, the time required extending from twelve to twenty-two days. The bars, when withdrawn, are found to be converted into steel of an exceedingly brittle character, and full of fissures. Numerous cavities are found to have been formed beneath their superficial laminæ, presenting the appearance which has given to the product the name it bears, of blistered steel. In order to solidify it, and to restore its malleability, it is necessary that it should be reheated and passed beneath heavy hammers, or between laminating rollers; but it is very difficult, if not quite impossible, to eliminate all its imperfections.

In the year 1740, a great improvement was made in England in the steel manufacture, by an obscure mechanic named Benjamin Huntsman. Huntsman's process consisted in fusing the ordinary steel, and casting it into solid ingots; but the method pursued by him was kept secret by its inventor, until at length it was disclosed by the cunning of a workman, who introduced himself into his shop under false pretences, and possessed himself surreptitiously of its details. Its general introduction proved to be of inappreciable advantage to all the mechanic arts. The defects of cemented steel, its want of homogeneousness, its numerous fissures and flaws, its imperfect ductility and malleability, detract greatly from its usefulness; while the only means by which these defects can be removed or diminished, frequent reheatings and hammerings, gradually deprive it of the important properties peculiar to steel, and reduce it toward its

original condition of soft iron. By the process of Huntsman, any description of steel may be expeditiously rendered homogeneous by fusion, without impairing the qualities on which the utility of this most important material depends. Each operation is, however, restricted to a small quantity, and large masses can only be obtained by employing many crucibles at once.

PUDDLED STEEL.

About a century had passed away after the introduction of the process of Huntsman, when the attempt was first successfully made to produce steel from cast-iron by the process called puddling; the same process substantially by which pig-iron is rendered malleable. In this process the carbon in combination with the metal is gradually removed by oxidation, and if the process be arrested at the suitable moment, the product will be found to possess the properties of steel of different degrees of hardness, according to the degree of decarbonization. Only moderate quantities, not exceeding four or five hundred pounds, can be transformed by this means in a single operation; and in order to obtain considerable masses it is necessary to remelt the product and to combine the contents of many crucibles in a single casting. Much skill is required to conduct this operation successfully, and it can only be performed in large establishments, provided with many furnaces, and with mechanical arrangements such as to permit the products of all to be promptly brought together at the fitting moment.

PRODUCTION OF LARGE MASSES OF STEEL BY KRUPP.

It is about thirty years since the manufacture of steel by puddling began to acquire importance. The facility of the process, as compared with cementation, determined speedily a great advance in this department of industry. It was soon found practicable to produce, economically, masses of a magnitude greatly exceeding any which had before been known. The manufacturer whose successes on a large scale were earliest to attract attention, was Mr. Krupp, of Essen, in Prussia. At the Universal Exposition of 1851, this gentleman exhibited a specimen of crucible steel weighing nearly two and a half tons. This, however, was greatly exceeded in 1855, when the same exhibitor presented at the Paris Exposition of that year a block of the same material, five tons in weight But these early achievements have been thrown entirely into the shade by the magnificent displays of 1862, in London, and of 1867, in Paris, at the first of which he exhibited an ingot of twenty tons, and at the second, another of the enormous weight of forty tons. On this last occasion Mr. Krupp presented also a monster gun of fifty tons in weight, which, if not cast in a single piece, was only not so because it was necessary to shrink the external rings on to those beneath them. The steel employed by Mr. Krupp in this manufacture is prepared by puddling from the spiegel ore of Siegen. His crucibles receive from

seventy to seventy-five pounds of puddled steel each, and are heated in furnaces, of which he has four hundred, capable of holding each from two to twenty-four crucibles. He produces more than eight hundred tons per week. The fractures and flexures of the massive specimens exposed by him near his great ingot, show the excellence of their quality, their fine and homogeneous structure, and their remarkable toughness.

While Mr. Krupp has thus demonstrated the possibility of producing steel in masses of any magnitude required to meet the exigencies of industry or to subserve the operations of war, the problem of economical production has not been so fully solved by him as could be desired. In the processes of puddling and remelting there is a large consumption both of time and of fuel. The consumption of fuel (coke or charcoal) approaches to, or exceeds, seven times the weight of the steel produced; and this is accompanied by a loss of material which is stated by Mr. Frémy at not less than thirty-five per cent. It must be added further that the process is not successful except with certain descriptions of ores, and that even with the purest hematites it furnishes inferior results.

BESSEMER STEEL.

The problem of producing cheap steel, of good quality and in large masses, remained, therefore, yet, in spite of the successes of Mr. Krupp, and of others whose displays in the present Exposition fairly rival his own, in great measure unsolved, when, about ten years ago, Mr. Henry Bessemer, of Birmingham, England, proposed the method, now known by his name, of transforming liquid iron, received immediately from the smelting furnace, or obtained by remelting ordinary pig-iron, at once, with scarcely any loss of time and no consumption of fuel, directly into steel.

Mr. Bessemer was not the first to attempt the conversion of carburetted iron into steel, although he was the first to invent a practicable process for accomplishing so desirable an object. In the year 1848, Newton, and in 1849, Marcy, patented in England methods by which they hoped to effect the same thing; the principle in both cases being to oxidize out the carbon by directing a stream of air, or of air mingled with carbonic oxide, upon the surface of the liquid metal in a reverberatory furnace. But so long as the action of oxidizing gases is confined to the surface, it is quite impossible effectually to decarburize any considerable mass of metal, or any mass at all, except at the expense of a disproportionate length of time and a considerable loss of the metal itself. These methods were therefore abandoned for others, which, though unsatisfactory in their immediate results, indicated very possibly to Mr. Bessemer the direction in which success was ultimately found. Mr. Nasmith employed blowing tubes to penetrate the melted mass; but instead of injecting air he introduced steam below the surface of the metal, having in view to effect two distinct objects at the same time. In the first place, by

means of the mechanical agitation produced, he aimed to effect a more thorough contact of all parts of the metal with the injected vapor; and in the next place, by the decomposition of the vapor itself, he expected to furnish oxygen for the removal of the carbon from the iron, and hydrogen for separating the sulphur and phosphorus. To a certain extent the effects anticipated were produced, but the decomposition of the water was attended with so large an absorption of heat, that the process failed through a too great reduction of temperature. To remedy this defect, it was proposed by Mr. Martien to employ a mixture of air and steam; and finally Mr. Bessemer adopted the plan of using air alone.

The idea of Mr. Nasmith, of acting upon the sulphur and phosphorus by means of hydrogen, is one which has been more recently revived, and with success (as mentioned below) by Mr. Berard, and it is employed by him as an improvement upon the Bessemer process; but the hydrogen is generated in an independent vessel, and is not produced by the decomposition of water at the expense of the heat of the metal which is itself to be operated on.

The Bessemer process is undoubtedly one of those remarkable inventions which from time to time transform a great industry, and exert at the same time an immense influence upon other industries dependent upon it. Like other important inventions it has had to make its way against the prepossessions or the prejudices of many whose opinions carry with them weight; and it has had to encounter the discouragements which unanticipated difficulties, always sure to arise in every untried path, bring with them to the pioneer explorer. One by one these obstacles to the success of the new process have disappeared. It has been tested on a grand scale by many judicious iron-masters; and in briefer time by far than has been the case with the greater number of the improvements by which the world has been ultimately most highly benefited, its merits have been acknowledged, and it has become the life of an immense, a well-established, and a daily-growing industry.

The doubts for some time entertained on the part of manufacturers in regard to the merits of the process of Mr. Bessemer are well illustrated by the language of the jury on steel manufactures, in the Exposition of 1862. After stating the earnest interest universally felt in the improvement of the production of this, the most useful of all metals, which had manifested itself in the presentation, during the eleven preceding years, of no fewer than one hundred and seventy-seven applications for patents for such improvements in England, of which one hundred and twenty seven had been actually issued, the jury go on to say, "Yet out of these one hundred and twenty-seven patents there is only one which has brought about any striking change in the mode of producing steel, or which has been attended with any real or practical commercial results, and this is the process patented by Mr. Bessemer. And even Mr. Bessemer himself does not contemplate that the metal or steel made by his process will supersede the steel made in the old-fashioned way, but rather that it will

become a substitute for wrought iron in most cases where large masses of metal are required." The jury go on to state what, in their judgment, are the peculiar characteristics of the Bessemer metal or steel; having formed their judgment partly from information received from Mr. Bessemer himself and other scientific and practical men, and partly from their own observation and experience. They say that "when nearly decarbonized it is a soft, homogeneous, useful metal, suitable for cannon, ship, and boiler plates, piston rods, slide bars, and generally for large forgings for constructive purposes;" but that, "when in this state it will not harden, and can only be welded with difficulty." Further, that "when a larger proportion of carbon is left in the metal, it is then difficult to obtain uniformity of temper or quality, and there is no certainty even that all the ingots from the same conversion will prove workable."

One of the members of the jury on this occasion was the eminent French chemist, Mr. Frémy. Mr. Frémy did not agree with his brother jurors; but, in the absence of experimental data, he hesitated to press his opposition. He resolved to make the process a subject of careful personal inquiry and study, and to this end he visited first the large establishment erected at Sheffield, in England, by Mr. John Brown, for the manufacture of Bessemer steel. Here, for the first time, he was a witness to the conversion into steel of a mass of cast iron, two tons in weight, in less than fifteen minutes. This admirable operation produced upon him, he remarks, a profound impression; but it was not in his power to test the quality of the steel produced, and all his colleagues of the jury maintained that it was incapable of receiving a uniform temper. He was assured that several establishments in England had failed in the employment of the Bessemer process, and Mr. Bessemer himself confessed that he had been completely unsuccessful in the treatment of certain descriptions of metal, containing sulphur and phosphorus, sent to him from France. Mr. Frémy left England, therefore, under the conviction that the process, though undoubtedly valuable, would never suffice to produce a metal which would compete with crucible steel; and as to the utilization of French pig-iron in this mode of manufacture, his doubts were more serious still. But all these doubts, he adds, were removed by a profound study of the process which he was subsequently enabled to make in a French foundry. This establishment, which had been for many years in existence under the direction of Mr. William Jackson, grandson of the enterprising individual by whom the process of Huntsman was first introduced into France, had been created for the production of steel by all the known processes, and it had been the first in France to add to these the process of Mr. Bessemer. The opportunities here offered to Mr. Frémy for pursuing the investigation to which he had resolved to devote himself, were all that he could desire. He assisted at more than thirty operations. He caused the crude iron and the steel produced from it to be weighed in his presence, that he might determine exactly the loss; he studied carefully the properties of the steel pro-

duced in every case; and he considers himself, therefore, qualified to pronounce authoritatively upon the value of the process itself.

As to the nature of this process, the several steps of which it consists, and the modifications which must be introduced into it according to the character of the crude iron employed, it is not the province of this report to speak. These matters will be treated by the committee on metallurgy, with the professional knowledge which their discussion requires. For the present, it is only the results which concern us. One important remark of Mr. Frémy may, however, very fitly be quoted here in passing. He says: "It had been hitherto admitted that the process of Mr. Bessemer was adapted to the refining only of certain silicious descriptions of iron; that it was not suited to the treatment of sulphuretted or phosphuretted metals; and even that our French charcoal irons would not develop heat enough to furnish a good product. The greater part of our French pig-iron was thus condemned to an exclusion which might be the ruin of our furnaces fed by charcoal. I am happy to be able to announce that this exclusion does not exist, and that our French irons, whether smelted with coke or charcoal, give excellent steel when treated intelligently in the new apparatus."

In regard to the properties which the products of the Bessemer process exhibit, the testimony of Mr. Frémy is very emphatic. He says: "I do not hesitate to declare that the Bessemer apparatus properly employed produces true steels, and frequently excellent steels. I have caused the Bessemer steels withdrawn from the apparatus to be subjected, in my presence, to all the tests which characterize steel, and the results have been invariably satisfactory. Often the Bessemer steels present an assemblage of qualities appertaining at once to cemented steel, to natural steel, and to cast steel. They are, in fact, tough when cold, and uninjured by heat; they weld easily, and they can be tempered to extreme hardness. I preserve specimens, which were prepared in my presence, which demonstrate all these precious properties. Bessemer steels may be made at will hard or soft. Mr. Jackson often asked me what kind of steel I desired to obtain, and the reaction, suitably managed, gave infallibly the species of steel which I had demanded." As to the loss in the process, Mr. Frémy finds it rarely more than ten per cent., and of this loss a considerable portion may be recovered. His conclusions are summarily stated as follows:

1. Bessemer steel, properly prepared, offers all the qualities which industry, or war, or the marine service, can demand of massive cast steel. It is homogeneous and harder and more resisting than iron; it can, according to the mode of fabrication, be produced with all the degrees of hardness which its applications require; it is hardened by temper; it welds and works under the hammer with more facility than ordinary cast steel.

2. Bessemer steel, which is always produced at a high temperature, is consequently very fluid at the moment of its formation, and contains

within its mass only a small number of bubbles. The fusion can therefore give it the desired form in the first instance, and the object may be afterwards finished, almost without loss, by hammering and rolling.

3. Refining for steel by the Bessemer method has become one of the most simple operations of metallurgy; it is accomplished in a few minutes; it can be committed to operatives of little skill; it presents the regularity of a chemical reaction; it does not depend in the least upon the dexterity or address of the workman; it replaces all the operations which constitute refining for iron, cementation, and fusing in the crucible.

4. The Bessemer apparatus gives easily, according to its capacity, one, two, three, or ten tons of cast steel. By combining several converters, and uniting their products, enormous masses can be obtained. One Bessemer apparatus of three tons will replace six or seven refining furnaces, nine puddling furnaces working twenty-four hours, and three hundred crucibles for the fusion of steel.

5. Almost all French iron, prepared from good mineral, whether by means of coke or of charcoal, will give a Bessemer steel of excellent quality when properly treated.

6. The consumption of combustible, which is considerable in the refining of pig iron, in cementation, and in fusing steel in the crucible, in a manner disappears in the Bessemer process of refining. The liquid iron can in fact be taken at the moment of its leaving the smelting furnace, and the blast can be furnished by water power. If it is thought more advantageous to prepare in the reverberatory furnace the metal for the Bessemer apparatus, it is known that the weight of combustible necessary will be only half that of the iron. The entire consumption in the Bessemer process, including the heating of the apparatus before the operation, does not amount to four-fifths of the weight of the steel obtained; whereas, by the old method, the weight of combustible employed is six or seven times greater than that of the product.

These statements, in regard to the value and importance of this remarkable invention, are deserving of especial consideration, since they are the conclusions of a man pre-eminently qualified to pronounce on such a question, and are announced only after a most thorough and persevering study of the process in all its phases. Since the publication of this report of Mr. Frémy, the Bessemer steel industry has received a much larger development than it had then acquired; and this is rapidly growing in every direction. In England, France, Sweden, and Austria, large quantities of the metal are annually produced, and the manufacture has been commenced in Prussia. Beautiful specimens are presented in the Exposition from all these countries. From the Atlas Works of Sheffield, England, belonging to John Brown & Co., are exhibited steel tubes for cannon nearly ten feet in length, and more than a foot in diameter, beautifully finished in the lathe, and showing a perfectly uniform, homogeneous, and compact structure. The same manufacturers exhibit also projectiles, spherical and elongated, of great size. The

spheres are finished under the hammer, and one of the largest weighs one thousand one hundred and thirty-six pounds, with a diameter of twenty inches.

Of steel plates for ship-building and other purposes, many thousand tons have been rolled in England during the last few years. A single firm in Sheffield (not represented at the Exposition) has prepared more than five thousand. The London journal, "Engineering," states that another firm is prepared to take orders for any quantity of Bessemer steel plates up to sixteen hundred-weight each, of which the sheared edges shall double over cold under the hammer without the slightest crack. Some of their plates, thirteen feet long, six feet four and a half inches wide, and seven-sixteenths of an inch thick, which though large are not of the largest size, are said to have given excellent results.

AUSTRIAN AND SWEDISH EXHIBITIONS OF BESSEMER STEEL.

The Austrian and Swedish exhibitions of Bessemer steel are particularly interesting, as furnishing illustrations of the variety of qualities which may be imparted to the metal by variations in the treatment during conversion. The government iron works at Neuberg have presented bars, plates, ingots, and manufactured articles, of this material, many of which have been subjected to flexure, fracture, and torsion, in order to show their toughness, soundness, and homogeneousness of structure. Some of these articles also bear a high polish. Seven different descriptions of metal are prepared at these works, which are classified and numbered according to the amount of carbon which they contain; No. 1 being the hardest, and No. 7 the softest.

At the Fagersta Works, in Sweden, the varieties are much more numerous; careful tests having been made not only by flexure, tension, and torsion, but also by compression, of specimens differing from each other by one-tenth of one per cent. of carbon, from 1.3 per cent. downward, and extended below 0.1 to almost absolute decarbonization. The behavior of the specimens submitted to compression is very striking. They are all more or less diminished in height, the softer by more than one-half; and yet no one of them has been crushed, or has betrayed any tendency to fracture on any part of its circumference. The effect of torsion is shown upon cylindrical bars, by the appearance of lines drawn on their surface originally parallel to the axis, but which have been converted, by the process of twisting, into spirals of beautiful regularity.

Bessemer steel from Austria is exhibited by two manufacturing establishments, and by the Southern Railroad Company of Styria. Among the specimens is a block made at a casting from a single converter, of three tons in weight. There are also boiler plates which show remarkable tenacity on being bent cold.

Not a single specimen of Bessemer steel is presented from Germany. This is attributed by some to the continued existence in that country of

the prejudice against which this invaluable invention has had to contend everywhere, but which has been, in great measure, overcome in France, England, and America, by the overwhelming and daily accumulating evidence of its merit. Moreover, the German producers, and especially the Prussian, having become pre-eminently distinguished for the magnitude and the excellence of their crucible steel manufacture, they cannot, without a natural reluctance, yield the palm in this magnificent concourse to those of any other nation; and they are, therefore, likely to be the last to adopt a process which may possibly at some day supersede that which they have themselves created, and which in their hands has produced so magnificent results. But by some, also, it is in no small measure attributed to a less worthy cause, and that is, the disposition to profit by the invention by availing themselves of the inadequate protection afforded by the German patent laws to the rights of the inventor, while they decry the invention itself in order to cover up this ungenerous practice. The editor of the journal above cited says: "The Bessemer steel makers in Germany pay no royalty to the inventor, and they are, therefore, not allowed to import their products into France, England, or any other country where Mr. Bessemer's patents are valid. It is, therefore, obviously to the advantage of these steel makers to keep their mode of manufacture a secret, *i. e.*, to deny that their steel is made in accordance with any patented plan, and thereby to secure to their products the possibility of importation into other countries without the payment of royalties. This being the case, the inducement to create prejudice against the quality of Bessemer steel, as compared with what is called 'cast steel,' or 'crucible steel,' is very great; and the consequence is that, out of a considerable number of establishments in Germany who produce Bessemer steel in large quantities, and of excellent quality as well, there is not one at the Paris Exhibition which uses the name of Bessemer for the products exhibited. We do not think that to be a just and fair mode of treating an inventor who has conferred so great a benefit upon the iron manufacturers of all countries." No, it is by no means just or fair, but it is the kind of justice and fairness which great inventors usually receive at the hands of their contemporaries. Mr. Bessemer has, in fact, been quite exceptionally fortunate. His rights have been respected in his own country and in some others, and he reaps a corresponding advantage. It has too often been the case that great inventors have not only been stripped of their rights, but have been left to starve among the people for whose benefit they had impoverished themselves. Such was the reward of Leblanc for the greatest discovery of his age in applied chemistry. Such came very near being that of Watt, for the most important mechanical invention ever made.

The importance of the new process for steel will not so much appear if, in considering the greater cheapness and facility with which the metal can now be produced, we regard those purposes only to which it has hitherto been applied, as when we turn our attention to the vast variety

of new uses for which it will hereafter be in continual demand. Iron, up to the present time the most valuable of all the metals, for the variety of its applications, fulfils, after all, but imperfectly many of the functions to which it is applied only because there is no better economically available. In the form of cast iron it is hard, but brittle; in the form of wrought iron it is tough, but soft. In either case it is deficient in elasticity. Steel possesses all the good qualities of iron in both its forms, and to a greater degree than either, while it has additional and no less valuable qualities which are not found in wrought or in cast iron. Nothing but its expensiveness has prevented it from being long since applied to the construction of all parts of machines which are to be subjected to strain or to constant friction; to the construction, for instance, of axles, of wheel-tires, of wheels themselves, of piston rods, of steam-engines in all their parts, of boilers, of propeller shafts, of fire-arms of all kinds, and especially of heavy guns, of armor for ships or for fixed batteries, of the hulls of ships themselves, of railroad machinery and rails, and of a multitude of minor objects important to industry which it is needless to enumerate. The very moderate prices at which Bessemer steel can be furnished cannot fail to cause it soon to take the place of iron for most of these purposes. It is obvious, from the mode of its manufacture, that, so far as the expense of labor and consumption of fuel are concerned, it can be produced even more cheaply than iron. Moreover, the peculiar manganesic ores, occurring only in certain localities, which have hitherto been found most advantageous, and to a certain extent indispensable, for manufacturing good steel by any process, have been satisfactorily and very simply replaced by Mr. Bessemer, by means of a manganesic iron artificially prepared.[1] No natural or eco-

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[1] It appears that the manufacture of this product, so interesting and valuable, after having been commenced under promising auspices, has been, at least for the time, suspended. The following statement, taken from the London "Engineering," explains the circumstances:

"In the history of the Bessemer process the name of ferro-manganese will, under all circumstances, have an important place. Though the manufacture of this substance has now been interrupted, or perhaps finally given up, by the parties who first succeeded in making it, practically and commercially, and may have proved unprofitable as far as the past and present state of the market, and of the steel manufacture, is concerned, there can be no doubt that with the further extension of the Bessemer process, and with the application of it to the manufacture of the softest kind of steel or malleable metal, such a substance will have to be again brought into the market, and it will ultimately find its place among the metallurgical products of every-day use in steel-making by almost all modern processes The manufacture of ferro-manganese was commenced, at Mr. Bessemer's suggestion, by Mr. Henderson, of Glasgow, who invented and patented a process for the production of alloys of iron and manganese, containing a high percentage of the latter metal. A Siemens furnace was erected for carrying out this process at the Phœnix Foundry, Glasgow, about three years ago, and the manufacture of ferro-manganese was commenced with apparently good commercial results, and certainly with the greatest success, as far as the quality of the product was concerned. The metal has a price in the market depending upon its percentage of manganese, the steel-makers paying £1 per ton of ferro-manganese for each per cent. of pure manganese contained in it. A ton of ferro-manganese, for example, guaranteed to contain twenty-three per cent. of manganese, was sold at £23 and at that price it was upon a

nomical obstacle, therefore, can any longer exist to prevent the substitution of steel for iron on a scale as extensive as the best interests of the industrial arts may require. And even supposing that, weight for weight, steel should for a time continue to be more expensive than iron, it must not be forgotten that it will always possess two especial advantages which may make it cheaper in the end, and possibly cheaper, also,

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par, as far as manganese is concerned, with the average of German spiegeleisen which (containing about seven per cent. of manganese) stood at £7 in the quotations of iron-merchants n this country.

"The mode of manufacture, as carried on in the Phœnix Foundry, consisted in mixing carbonate of manganese, a substance obtained in soda works as one of the products of the manufacture of bleaching powder, with an almost equal quantity of a pure calcined iron ore, also drawn from a soda works, in which it formed a kind of refuse. The original substance which yields this iron ore is a kind of iron and copper pyrites, found in large quantities on the south coast of Spain."

After describing the method of separating the sulphur and copper, leaving the oxide of iron purified from all its admixtures, and in a state of mechanical aggregation very suitable for reduction, the writer proceeds: "This iron ore, obtained as a residuum or waste product from the copper works, was the second raw material employed by Mr. Henderson for making ferro-manganese. The two substances, viz., carbonate of manganese and oxide of iron, were mixed with charcoal powder or coke dust, and the whole mass charged without crucibles into the Siemens furnace. The reduction of both metals, iron and manganese, took place simultaneously, and the percentage of manganese increased with the temperature, but not with the quantity of manganesic matter put into the charge; all surplus of the latter going into the slag and eating through the fire-bricks of the furnace in a remarkably short time. This destruction of bricks by the chemical action of the manganese slag was, in fact, the great difficulty in this process. It went so far that the powder carried into the regenerators by the current of gases, and afterward heated when in contact with the bricks, melted and destroyed even these portions of the furnace, and necessitated frequent repairs. The bottom of the furnace was lined with graphite, and this stood better than the exposed surfaces of the fire-bricks in the other portions. The metallic alloy of iron and manganese produced, ranged in its percentage from seventeen to thirty per cent. of manganese, and it was very free from other impurities. The Bessemer Steel Works employed it for the manufacture of the softest articles, such as boiler plates, &c., but its high price prevented its use for the manufacture of rails, and consequently the demand for it remained smaller than was originally expected. The manufacture of this metal has, therefore, not been continued at the Phœnix Foundry, and consequently this useful and valuable material does not at present exist in the market. Steel-makers are now entirely dependent upon spiegeleisen for the necessary supply of manganese; and although they have succeeded in making the spiegel give sufficiently good results, there still remains an acknowledged want of a richer manganesic alloy; and this will probably make itself felt all the more when the attention of Bessemer steel-makers is more largely turned to the manufacture of armor plates."

The following is one of the methods which have been practiced by Mr. Bessemer himself in the preparation of ferro-manganese for the uses of his own works. He has been accustomed to melt iron of the purest qualities, and to granulate it, when melted, into shot, by pouring it upon a revolving wheel throwing the particles into cold water. This small iron shot is then placed in a crucible, or in a reverberatory furnace, along with a powdered mixture of very fine anthracite coal and black oxide of manganese, and subjected to heat. The heat which will decompose the oxide of manganese is always sufficient to melt the iron, and to form a perfect mixture of the two metals. The anthracite, of course, goes to carburize the oxygen of the oxide, and passes away, thus leaving a comparatively pure ferro-manganese. With this compound any required amount of manganese may be introduced into a "blow" of Bessemer steel, and that without at the same time adding a hurtful proportion of carbon, which is too often the case in the use of spiegeleisen.

in the beginning; for the relative strength of the two materials is so greatly in favor of steel, that the weight of every heavy article in which it replaces iron may be considerably reduced, thus securing an economical and a mechanical advantage at the same time.

STEEL RAILS.

The durability of steel so much exceeds that of iron, that the expense of maintenance of any construction in which it is employed will be greatly diminished. These advantages are illustrated in the experience of the Northern Railway Company of Austria, which was one of the earliest to experiment upon rails of Bessemer steel, and which exhibits specimens of its rails in the Exposition. These rails were at first employed by this company only by way of trial upon the most frequented parts of their line. The results proved so satisfactory as to induce the company to lay them down over the whole line. Seventeen miles laid down a year ago (1866) as yet show no signs of wear. Two hundred and fifty miles additional were ordered in 1867. But the results of the experiments made were not merely satisfactory in regard to the increased durability of the new material. They demonstrated that the section might be materially reduced. With a weight per yard of only forty-five pounds, the company obtained a steel rail having double the strength of the iron rails of larger section previously employed by them. The cost to the company per ton of iron rails having been from sixty dollars to seventy dollars, and that of steel rails being from ninety dollars to one hundred dollars, the expense per running mile is still kept nearly within its original limits, with a very great improvement in regard to strength and durability.

The French railway companies are also extensively introducing rails of Bessemer steel upon their roads. These rails, as manufactured at the principal French works, cost from sixty dollars to seventy dollars per ton.

BESSEMER-STEEL BRIDGE.

The largest single construction of Bessemer steel yet made, (1867,) so far as the information of the present reporter extends, is, however, the bridge on the Quai D'Orsay, beneath which communication is established between the Exposition on the Champ de Mars and the Berge on the Seine. This bridge is a single arch, twenty-five metres (eighty-three feet) in span, and two hundred and seven metres (six hundred and fifty-eight feet) in breadth. The arch is formed of eleven parallel ribs, which are connected with a corresponding number of horizontal girders above them by means of a lattice-work patented by Mr. Joret, the constructor. It is the archway only which is constructed of steel, the structure immediately sustaining the road being of iron. The following interesting particulars in regard to this bridge are taken from a notice in the London journal, Engineering:

"The bridge was tested before being opened for traffic with a load of five hundred kilograms on the square metre, or one hundred and two and a half pounds per square foot of its surface, under which test the deflections were carefully measured, and were within the limits given by the calculation. A further test has been made by two wagons loaded with twelve tons on one pair of wheels, and drawn by five horses each, these being drawn forward and backward, the deflections being at the same time measured by means of thirty gauges placed at different points under the bridge. The mean deflection under this load never exceeded seven millimetres, or hardly more than one-fourth of an inch, leaving no measurable permanent set, and the bridge was opened by the government authorities to public traffic 'without reserve,' *i. e.*, the bridge has been proved strong enough to carry any load which ordinary road traffic can bring to bear upon it. The traffic has never since been restricted or stopped, and no signs of weakness have shown themselves. The bridge is fixed in its place temporarily only, as it has been constructed for another place, to which it will be removed after the close of the Exhibition, and it is therefore put together in all its principal joints with screw-bolts, which will afterwards be replaced by rivets when the bridge shall be erected at the point of its ultimate destination. The construction is on the patent principle of Mr. H. Joret, of Paris, one of the contractors for the Exhibition building. Its peculiarity consists in the mode of connecting the arch and the straight girders which carry the roadway by means of lattice-work riveted to prolongations of the central web.

"The lattice-work and the superposed structure are made of iron, since the sections of these parts are already sufficiently reduced to allow of no further reduction by the application of steel; but the carrying parts of the structure, *i. e.*, the arches, are made completely of Bessemer steel, rolled at the Terre Noire Works, Loire, in France. These works belong to a company who possess extensive mining property in several localities in France, and have a good reputation for the good and uniform quality of the steel produced, and they have principally laid themselves out for rolling plates, flats, angle steel, and rivet steel, the materials for bridge construction and civil engineering works, while the other Bessemer steel works in France have devoted their operations more especially to the production of railway material and of forgings of great weight. The calculated maximum strain brought upon the Bessemer steel under the test load is ten kilograms per square millimetre, or 6.35 tons per square inch, while the experiments previously made with this material showed that a load of twelve kilograms, or 7.62 tons, per square inch, would be fully admissible, and within the limits of safety.

"The arch consists of eleven ribs, or principals, connected with the straight girders above, which carry the level roadway by means of Mr. Joret's lattice-work, which allows of a reduction in the sizes and sections of these bearings, on account of its distributing the load upon a greater number of carrying points than is usually reached. The structure has

a very light and graceful appearance, and is considered very economical in point of material and work. Mr. Joret has applied the same principle to several other bridges built by him in France and abroad, among which is bridge at Sennecey, over the Saône, in five arches of one hundred and fourteen feet ten inches span each, the bridge at Épierre, over the Arc river, in Savoy, and the bridge of Valvins, over the Seine, near Fontainebleau, in five arches of seventy-two feet one and a half inch span each."

BERARD'S PROCESS.

Since the introduction of the Bessemer process no step of advance has been taken in the progress of steel manufacture which can compare with it in importance. Some valuable modifications have, however, been introduced into it, having in view the object of eliminating from the iron the elementary substances which are so often combined with it, and of which the effect is in general to injure the quality of the final product. These, which are sulphur, phosphorus, arsenic, and silicon, are, like the carbon, oxidizable, and are, therefore, in a measure, removed in the process of conversion. The elimination might be carried further by prolonging the period of oxidation, but the effect of this would be to decarburize the metal too considerably, and also to oxidize a quantity of the iron itself, which would be at least proportional, and might be more than proportional, to the quantity of the injurious substances removed, so that the metal remaining would not be improved in quality, and might even possibly be injured.

It is, however, well known that the affinities of sulphur, phosphorus, and arsenic for hydrogen are very great, while hydrogen at the same time reduces iron oxides. And it is further true that the compounds formed with hydrogen by the substances above named are gaseous at ordinary temperatures. These considerations suggest the advantage of acting upon the liquid metal which has been sufficiently decarburized either in the puddling process or in the process of Mr. Bessemer, by means of a stream of pure hydrogen gas, or, since that would not be economical, of mixed and compound gases in which hydrogen predominates. This is the principle of the process introduced Mr. Berard, already mentioned in another part of this report, which he applies in a puddling furnace of peculiar construction on the general plan of that of Mr. Siemens. This furnace has two independent hearths, separated by a bridge, and the flame enters alternately on one side and on the other. The oxidation is effected by introducing into the metal, when the fusion is complete, plunging tuyeres which blow the air through it as it is blown through, somewhat differently, in the Bessemer converters. A tumultuous agitation takes place during this part of the process; drops of metal are thrown up which oxidize in the air, and falling back are more or less reduced again. The hearth itself becomes excessively heated, and in this way stores up a supply of heat to be expended in the subsequent

reducing process. At the end of ten minutes the flame is reversed, and the plunging tuyeres being withdrawn from the metal thus far acted on, another set are introduced into that upon the second hearth.

It will be understood, from the relative situation of the two hearths, that the flame, from whichever side it enters, acts upon both hearths successively: but that it expends its oxidizing power on the first, and becomes on the second a reducing flame. The effect, however, of the superficial contact of this flame upon the metal is not alone relied on, but plunging tuyeres are employed to force reducing gases through the mass, in the same manner as that in which the air was introduced previously. These gases consist of a mixture of carburetted hydrogen, oxide of carbon, and hydrogen pure. They are generated in a special apparatus, in part by the decomposition of superheated water, and are carefully purified. Before reaching the tuyeres they pass through a heating apparatus where they are raised to a high temperature.

The action of the gases is not simply a volatilization of the injurious elements. There is also a greater or less absorption of carbon by the metal; and this can be varied by employing mixtures of the gases in different proportions. There results from this fact the important advantage that the process may be accelerated or retarded according to the length of time which may experimentally be found necessary to get rid of the impurities in a given description of pig-iron, without either decarburizing too far the product, or increasing the waste of material. With gray cast iron of medium quality the whole operation, for a mass of two or three tons, lasts from half an hour to three-quarters. The oxidizing and reducing operations alternate at intervals of from ten to twelve minutes. When the purification is complete the excess of carbon in the metal is removed by oxidation, either by adding pure oxide of iron or by the action of the air. The state of advancement of the process is tested from time to time by taking samples.

One great advantage of this form of furnace and of this process is, that the process is continuous, the charges on the two hearths being brought alternately to the completed condition, drawn off and replaced by fresh charges, without interrupting the operation; and while both hearths are occupied, the bridge intervening affords a convenient place for heating the pigs in advance of their introduction into the furnace.

In the use of this process, it is affirmed, by those interested in it, that a single furnace will turn out fifty or sixty tons of steel a day; and such a furnace, placed in connection with a smelting furnace, from which it may receive the liquid metal directly, will, according to the same authority, furnish steel in ingots cheaper than iron. The loss in the process is stated not to exceed eight or ten per cent.

There are claimed for the steel produced by this process qualities superior to those of ordinary Bessemer steel. It is perfectly homogeneous, fine grained, soft before temper, tempers very easily, and may be made remarkably hard. It also bears reheating uncommonly well. In a series of experiments made by Mr. Charpentier, of Montataire, it showed no

sensible change after ten repetitions of this process with intermediate tempering. After the first experiments its density increased, till it became at length 8.92, a density which has not been before attained for steel.

PRODUCTION OF STEEL FROM THE ORE BY SIEMENS'S PROCESS.

Mr. Siemens himself has also recently patented a mode of applying his furnace to the direct production of steel from the ore. He exhibited a specimen of the steel so produced in the Exposition. The following outline of this plan is taken from the London Engineering:

"The furnace is constructed somewhat similar in form to the Rachette furnace, viz., with two parallel sides sloping downwards, so as to form a kind of trough between them. The ore is charged at both sides on the top of the furnace, and slides down the inclined planes of the two sloping sides. At the bottom of the furnace the gases from the producer and the necessary supply of air are admitted, and produce an intense flame, the products of combustion rising upwards through the masses of ore, which are acted upon in a similar manner to that in the blast furnace. With very pure manganesic ores it is possible to manage the process so as to decarburize the newly produced iron immediately after it is made, or rather the heat can be made sufficient for melting a metal which contains less carbon than common cast iron as made in the blast furnace, and at a lower temperature. This metal is natural steel, or 'raw' steel and, made from ores of sufficient purity, may have all the qualities of the best cast steel. The specimen exhibited by Mr. Siemens, and made, we understand, at his Model Steel Works in Birmingham, where the first experiments with this new process have been carried out, is of very fair quality as far as can be judged from its general appearance and fracture. We have been informed that Mr. Siemens is now erecting a similar furnace at Barrow-in-Furness, intending to make steel from hematite ore direct, at the Barrow Steel Works. Mr. Siemens's new process, if successful and economical, would do away with blast furnaces, and all other processes for making and refining iron now in use; but it is too little advanced at this moment to allow of a judgment of the probability of its practical success, to say nothing about relative economies. Its practicability remains to be established. But if we consider how much the same inventors have already established, how difficult it was to believe in the success of the Siemens furnace itself when first brought out, and how completely they have succeeded in this respect, we may be justified in entertaining some hope that this new invention will ultimately prove equally successful, although at present it may appear very revolutionary and contrary to adopted notions."

Considering the rapidity with which, during the last twenty years, improvements have followed each other in this most important branch of productive industry, it is not too much to predict that the time is very near at hand when the manufacture of steel directly from the ore will have superseded all other processes.

II.—ARTIFICIAL STONE.

In reviewing the useful inventions of comparatively recent date, it is impossible to overlook the great advances which have been made within a very few years in the artificial production of a material which, for the ordinary purposes of architecture, and even, to a certain extent, for the uses of higher art, possesses all the qualities of durability and beauty which belong to natural stone. No visitor to the Exposition of 1867 could have failed to be struck with the large number and variety of objects, frequently extremely elegant, which presented themselves on every side, but especially in the French and Prussian sections of the park, formed of what is called *béton aggloméré*, or with the still more beautiful objects in the English section, made of the artificial marble of Mr. Ransome.

BÉTON AGGLOMERÉ.

As to the class of objects first mentioned, the admiration of most visitors could not but have been mingled with some surprise, on learning that the material which exhibited such hardness and solidity and great specific gravity, and in its exposure to the weather during the several months that the Exposition lasted gave evidence of being so unalterable under atmospheric influences, was yet, so far as its composition is concerned, nothing more than common mortar with lime in very small proportion to the sand, and sometimes (not always) with a small addition of hydraulic cement. It differs from mortar only in being mixed in the preparation with a great deal less water, and being compacted by heavy ramming.

The agglomerated *bétons* have been extensively introduced in France in the construction of heavy public works, and in the erection of private dwellings. Nearly forty miles of the sewers of Paris have been constructed wholly of this material. All the foundations and basements of the palace of the Exposition, and other heavy structures in the Champ de Mars, those of the immense military barrack recently erected on the island of the city, the railroad bridge of Ste. Colombe on the road from Lyons to Marseilles, a very large number of substructures for private houses, some houses entire, and innumerable foundations for the support of heavy machinery, have been constructed in the same way.

The manufacture as now generally practiced was originated by Mr. Coignet, a French engineer, whose name is generally associated with the process. The following particulars in regard to the Coignet *béton* are gathered from several sources, the most interesting being derived from a paper on the subject, published by Mr. A. Paul, civil engineer of Paris.

This substance is compounded of sand in large quantity, with lime in smaller, say in the proportion of five to one, more or less, and also, if rapid setting and unusual hardness are desired, with a quantity of cement, hardly more than one-quarter of the quantity of lime, the pro-

portions being estimated by volume and not by weight. This mixture, in a condition nearly dry, and reduced to the form of a stiff paste, by being ground and worked up in mills constructed for the purpose, is introduced into the moulds designed to give it form, and compacted by repeated blows of a heavy rammer. The result is the production of a copy firm enough to allow the removal of the mould at once, by the separation of its parts. The copy is perfect, since the yielding material, under the heavy impact of the ram, has been driven into all the minute lines of the mould, and all the delicate traceries of the ornamental work. On exposure to the air the block rapidly hardens, and it has soon all the solidity of natural stone.

The effect of the successive processes of grinding and ramming is singularly to increase the specific gravity of the product. The reduction of volume, when the bulk of the compacted mass is compared with that of the materials out of which it is composed, is nearly as two to one, (1.7 to one,) and the weight per cubic foot becomes about one hundred and forty pounds. Simultaneously with the increase of weight, there occurs a very remarkable increase of strength; the resistance of many specimens to compression amounting to more than two and a half tons to the square inch.[1] An ordinary mortar made with precisely the same materials will be crushed by a pressure of probably less than five hundred pounds.

The explanation of this greatly increased cohesive strength may perhaps be found in the following considerations:

In mixing mortar an excess of water is always employed, and this occupies much space, and by separating the molecules of lime prevents their union, or acts unfavorably to what is called the setting of the mortar. If we suppose this setting, in the case of lime or of cement, to be an actual, though perhaps confused, crystallization, whether of hydrate of lime, or of the silicate and aluminate of lime, mixed or combined, which constitute, in different proportions, hydraulic limes and cements, it follows that this crystallization will be so much the more energetic in measure as the water present in the mortar in excess during the preparation is more effectually eliminated, and that in the same proportion the union of the sand, lime, and cement will be more intimate.

It is the opinion of the engineer whose paper has been cited above, that the hardening of the compacted mass is not exclusively due to the physical properties of the lime and cement in their original condition, but is owing also, in a measure, to the conversion of these substances gradually into carbonates, and that this conversion goes on the more rapidly and becomes the more complete in proportion as the lime is more finely divided.

Hydraulic lime should be used in this preparation. Fat lime may be employed, provided that a sufficient proportion of cement be added to

[1] Specimens of very superior bétons have even resisted crushing pressures approaching to four tons per square inch of section.

give it the hydraulic character. The lime should be well burned; lumps which seem to be overburned or underburned must be rejected. It is slacked by sprinkling, and afterwards heaped up and allowed to lie some days in order that it may acquire its maximum of volume and become thoroughly disintegrated. It is then sifted through No. 35 wire gauze. In this powdered condition the slacked lime may be kept for lengths of time.

It has been proved by the inventor, Mr. Coignet, that all kinds of lime, even the most common, after a while become as hard as the best. The only difference is in the promptness of the setting. In explanation of this fact, it is suggested that the ultimate hardness is probably due to the formation of the carbonate.

The cements employed in the manufacture of these *bétons* are in general the heavy and slow setting cements. The sand preferred is river sand, mixed with particles of stone of from one to five millimetres in diameter. If the sand is too coarse, the resulting masses will be rough; if too fine, it separates too much the molecules of the lime, retards the setting, and is prejudicial to the strength and durability of the resulting product. Pit sand answers very well; but in order to produce a result equal to that obtained with river sand, it is necessary to increase the proportion of lime and cement.

In mixing the materials, they are rudely measured, spread out on the ground, and turned with a shovel until the mass becomes homogeneous. They are then introduced into a tempering mill, and subjected to a very energetic grinding; water being added sparingly from time to time, and only in sufficient quantity to give the mass cohesiveness, and bring it to the form of a paste as stiff as can be conveniently worked. The importance of this part of the operation is very great, since the rapidity of the setting and the degree of the ultimate hardness will depend upon the minute subdivision, which is the effect of the grinding in the mill, of the particles of lime and cement.

The tempering mill is one which has been constructed specially for this purpose. It is of rolled iron, cylindrical in form, and has a vertical arbor in the centre, armed with knives set spirally around it. At the bottom the cylinder is perforated with many holes, through which the material is expelled by the pressure of a cycloidal appendage attached to the arbor below the knives. The rapidity of the expulsion may be controlled by raising or depressing a cylindrical gate, resembling the gate of the Fourneyron turbine, the process being retarded as the number of holes uncovered is diminished. As the tempered *béton* is expelled in the plastic condition at the bottom, additions are made to the quantity in the mill, by introducing raw material at the top.

The plastic *béton* thus obtained is thrown into the moulds in strata of from one to three inches thick, and beaten down and compacted by repeated blows of a heavy ram, weighing from fifteen to twenty pounds, applied all over the surface. The beating of a stratum having been com-

pleted, its surface is scratched and roughened by means of a rake, for the purpose of forming a secure bond with the stratum next to follow.

Two kinds of moulds are employed, according as the object moulded is to remain permanently in the spot where it is formed, or is to be removed and built into a structure elsewhere. In the first case, the moulds are a species of coffer built up temporarily of wooden walls united by horizontal cross-pieces, which are secured by bolts. To the interior of these coffer walls may be affixed the moulds necessary to produce architectural forms, or the ornaments and decorations of staircases, portals, windows, &c., so that entire walls may be built in mass, with every appearance of being sculptured out of stone. For the preparation of portable blocks, the moulds are more varied in construction. They take the form of every description of object of which stone is the usual material, and serve to produce vases, urns, busts, statues, or simple cornices and friezes.

The following proportions are given by Mr. Paul as those employed in the great monolithic structures of Paris, including the sewers and the substructures of the Exposition, viz: five parts of sand, one of lime, and one-quarter of one part of cement in bulk. Such is the rapidity with which constructions in this material are carried on, that in six or eight hours after beginning work on a given length of sewer, it becomes safe and practicable to remove and advance the centres; and in four or five days after a section has been completed, it may safely be turned over for use.

For arches with a pitch of one in ten, the proportions are, for the sand and lime the same as given above, but the quantity of cement is doubled. The groined arches of the ventilators of the Exposition, and of the substructures of the gallery of refreshments surrounding the Exposition palace, were constructed to this pitch, and thus a floor of vast dimensions was supported by isolated columns one foot in diameter and distant ten feet from each other in all directions. At the crown of the arches this floor was but a little more than five and a half inches thick. The span of the basement arches of the city barrack is nearly twice as great, being 18.3 feet, and these arches are built to the same pitch. At the crown, in this case, the thickness of the material is nine inches. One month after the completion of one of these it bore a weight of forty-eight thousand kilograms upon twelve square metres of surface, or of forty-eight tons upon a surface of ten feet by twelve.

A church has been constructed at Vésinet of this material entirely, the whole being a mass of *béton* without joints. The pit sand of the neighborhood was used, and the lime and cement were in the proportions first given above. But the pavements were made of a *béton* richer in cement; the quantity of this ingredient being made, for this part of the construction, equal to that of lime. These pavements were very carefully rammed and smoothed with the trowel. In the lumber mill of Aubervilliers, the arches of the substructure, built of the Coignet *béton*, are twenty-

eight feet in span and fourteen inches thick at the crown. All the machinery of the saws is firmly fastened to the floors formed by these arches, by means of cramp-irons secured with lead, without having occasioned any injury to the structure during all the time the mills have been in operation.

The most important of the benefits which are to result from the use of the agglomerated *bétons* is probably to be looked for in the superior stability and strength which they are destined to give to the foundations and basements of ordinary dwelling-houses. The usual mode of forming such constructions at present is to employ a certain amount of cut stone at intervals, and to fill up the intervening spaces with rubble masonry. The entirely dissimilar character of these two kinds of masonry, with the great number of bonds or surfaces of junction between them, produces unequal settling and the consequent cracking of the walls. Walls which are constructed of agglomerated *béton* are not liable to such accidents. Their whole mass forms but a single homogeneous block, stronger than even the rock on which it rests as a foundation. From the fact of their continuity, their weight is distributed over the entire area of the foundation, and no settling can take place so unequally as to produce fracture.

In a dwelling of five stories, in Miromesnil street, Paris, constructed of a single mass of *béton*, a staircase of the same material runs in helicoidal form from the basement to the highest floor, moulded in the position where it stands.

At the Exposition, there were presented specimens of the various applications of this important material, including a pavilion, as illustrative of its adaptedness to building in mass, lintels, cornices, friezes, paving slabs, troughs, garden benches and tables, vases, monuments, urns, statues, and nearly every other important object in which stone is commonly employed, whether for useful or for ornamental purposes. As scarcely ten years have passed since Mr. Coignet's first experiments were made, and as it is only within the last two or three that the process has been perfected, or at least that its merits have been recognized, the *béton aggloméré* must be regarded as one of those new and useful things which the Exposition of 1867 was first to bring conspicuously before the world. At the Exposition of 1862, the efforts which, up to that time, had been made in this direction, inspired in the jury in charge of the subject so little confidence that the report of that body disposed of them all in the following summary manner: "Many artificial stones which at first sight appear admirably adapted for this purpose [building] are found, when exposed to this unerring test, [actual experience of some years,] to be utterly wanting in durability. No artificial stone can, therefore, be considered durable as compared with natural stone until it has undergone the test of long experience;" a test which the jury were not disposed to think had as yet been satisfactorily sustained by any such composition known to them.

The crushing weight which the *béton* of Mr. Coignet is capable of

resisting has been stated at four hundred kilograms per square centimetre, or nearly fifty-four hundred pounds to the square inch. Its resistance to a force of tension is thirty to forty kilograms the square centimetre, or four hundred to five hundred and forty pounds per square inch.

RANSOME ARTIFICIAL STONE.

More remarkable than the agglomerated *bétons*, or than any other form of artificial building material yet invented, is the unique composition of analogous character exhibited by Mr. Frederick Ransome, of London. This material is equally adapted to heavy constructions and to objects of art and ornament. Its strength is very extraordinary, greatly exceeding that of the sandstones and of most of the harder natural rocks in common use for architectural purposes, to some of which it nevertheless exhibits a striking resemblance in appearance. From the nature of the process of manufacture, it may be variously colored so as to represent the darker marbles; or, in case white sand is selected as the basis, it may be made entirely colorless. Any kind of clean sand may be employed to form the bulk of the composition. The cement by which the particles are bound together, when the process of transformation is complete, is silicate of lime. A description of the interesting process, by the application of which, out of the most incoherent materials, great masses of solid rock or ornamental objects of every variety of pattern are produced in the works of Mr. Ransome in the course of a few hours, was published during the continuance of the Exposition in Mr. Colburn's London journal Engineering, and this account so fully exhausts the subject, and is at the same time so lucid and satisfactory, that it is here substituted instead of the notice intended originally to occupy this place:

"If Mr. Ransome has not found the philosopher's stone, he has at least produced a stone worthy a philosopher, and which promises to become the stone of the ages. For it appears to have elements of great durability, and it certainly possesses every other quality desirable in building stone, whether for structure or ornament. Although five years are not five centuries, chemistry has analyzed even the tooth of time, and can produce, within the period of a comparatively brief experiment, results identical with those of ages of atmospheric corrosion and disintegration. Mr. Ransome's stone has been boiled, and roasted, and frozen, and pickled in acids, and fumigated with foul gases, with no more effect than if it had been a boulder of granite or a chip of the blarney stone. It has been boiled and then immediately placed on ice, so as to freeze whatever water might have been absorbed, and it has been also roasted to redness, and then plunged in ice water, but without any sign of cracking or softening, superficially or otherwise. Nor does its durability rest alone upon such evidence as this, for it is of the simplest chemical composition; and chemistry and geology alike testify to the durability, if not the indestructibility, of a stone which is nearly all silica, like flint,

and onyx, and agate, and jasper. It has no oxidizable constituent; for silica, or silicic acid, is already oxidized, and thus it is unalterable in air; and as the new stone is almost impermeable, it will suffer little, if any, injury from moisture or frost.

"And how marvellous, for its simplicity and beauty, is the process by which this stone is made! Some toiling mason or other, hewing in the quarry or in the builder's yard, must have wished, before now, that stone, like iron, might be melted and run in moulds even though his own occupation were thus at an end. Did he ever, when by the sea-shore or by a sand-pit, think of cementing indissolubly together the countless millions of grains into solid rock? Mr. Ransome, no mason, however—unless he be, as he may be for anything we know, a member of the mystic brotherhood—did think of this. And he tried every cement he could lay his hands to, and did not succeed. The sand became little else than mortar by such sticking as he could effect. But he found out, at last—and we are speaking of a time more than twenty years ago—that the best sandstones were held together by silicate of lime. And so he set himself to work to produce this substance, indirectly, from flints, of which plenty could be found for the purpose. But the flints had to be liquefied first, and how could this be done? Not by heat, nor would caustic soda touch them, so the chemist said. Flints might be boiled in a caustic solution for a week together, so long as the boiler was an open one, and lose very little by the operation. But by-and-by Frederick Ransome made one of the most unexpected discoveries in chemistry, viz., that when boiled in a caustic solution, *under pressure*, flints would melt almost like tallow before the fire. But we are not about to give the long history of the invention. With flint soup, or silicate of soda as a liquid, the question was what other liquid would, in mixing with it, turn both into an enduring solid? What other liquid would turn both into silicate of lime, the substance he was seeking? When he found that chloride of calcium (in solution) would, when mixed with silicate of soda, turn both into flint, or something very much like it, the road was clear, and the manufacture of stone from sand was as simple and as beautiful a process as the making of Bessemer steel from pig-iron by blowing air through it when in the melted state.

"During the month of June, 1867, on the occasion of a visit of a party of about one hundred and eighty gentlemen, comprising heads of public offices and boards, chemists, geologists, engineers, architects, and others, to the new works of the Patent Concrete Stone Company, at East Greenwich, Mr. Ransome showed and explained the whole process of making stone from sand, and exhibited some hundreds of the objects and ornaments, many of them of great beauty, already made to the order of architects and builders for various new buildings in England and abroad.

"The sand, a clean-grained, slightly brownish sort, just such as a dishonest grocer might select for increasing the gravity, specific or otherwise,

of his sugar, comes from near Maidstone. There is no end to the quantity of it, and we believe it costs less than three shillings a ton in the Thames. There are flints enough for a hundred years to come brought up from the chalk pits at Charlton; and the caustic soda and the chloride of calcium, the latter a waste product of the soda manufacture, are bought of the wholesale chemists. The silicate of soda is made from the flints and caustic soda as follows: The flints are heaped upon iron gratings within a series of cylindrical digesters, of the material, size, and form of small steam-boilers. A solution of caustic soda is then added; the digester is then closed steam-tight, and the contents are boiled by steam of seventy pounds taken from a neighboring boiler and led through the solution in a coil of iron pipes. The solution of caustic soda is prepared of a specific gravity of about 1.200. The flints are dissolved into 'soluble glass,' and are drawn off in that state as a clear though imperfectly liquid substance, which is afterwards evaporated to a treacly consistency and color, and of a specific gravity of 1.700.

"The sand is completely dried, at the rate of two tons an hour, within a revolving cylinder, through which hot air is forced by a centrifugal fan. A small portion of finely ground carbonate of lime, say Kentish rag, or even chalk, is mixed with the sand, the more closely to fill the interstices; and each bushel of the mixture is then worked up in a loam mill along with a gallon of the silicate of soda. Thoroughly mixed with this substance, the sand has a sticky coherence, sufficient to enable it to be moulded to any form, and, when well rammed, to retain its shape, if very carefully handled. In this condition—moulded, of course, and anything that can be done in founder's loam may be done in this sand, sticky with silicate of soda—in this condition it is ready for the solution of chloride of calcium. The instant this is poured upon the moulded sand, induration commences. In a minute or so little lumps of sand, so slightly stuck together by the silicate of soda that they could hardly be kept from falling to pieces within the fingers, were solidified into pebbles so hard that they might be thrown against a wall without breaking, and only a short further saturation was necessary to indurate them throughout. In other words, on the instant of contact, the silicate of soda and the chloride of calcium mutually decompose each other and reunite as silicate of lime and chloride of sodium, the former practically indestructible in air, the latter, common salt, perfectly deliquescent and removable by washing, although the stone, *after* the washing, is impermeable to water. Plaster of Paris does not set quicker than silicate of soda and chloride of calcium.

"The chloric solution is first ladled upon the moulded sand, and, the hardening going on, the objects are afterwards immersed in the solution itself, wherein large pieces are left for several hours, the solution being boiled in open tanks by steam led through it in pipes. This expels any air which may have lodged in the stone, and possibly heightens the energy of union with the silicate.

"After this the stone is placed, for a longer or shorter time, according to the size of the object, under a shower bath of cold water. This is not, by bathing, to convert it into Bath stone, although were the Bath stone a sand stone instead of an oolitic formation, this name would do as well as any. The salt, or chloride of sodium, deposited throughout the interstices, is sought out and washed away, in brine, by the water, and were it not that a portion of undecomposed chloride of calcium is also washed out, this brine might be profitably evaporated for common salt. Now this searching out of the salt by the water would appear to prove that the stone was perfectly permeable, but, by one of those paradoxes with which chemistry abounds, the stone, when once freed from salt, is almost impermeable. The action is one which, if it can be explained at all, can only be explained as one of the phenomena of dialysis, as experimentally investigated by Professor Graham. There is no doubt whatever that salt has been deposited everywhere throughout the stone, no doubt that it is afterwards completely washed out, and yet the stone as effectually resists the passage of water afterwards as if it were granite or marble.

"It is not necessary to describe the variety of objects that may be made in the new stone. It is practically a fictile manufacture, although not indurated by fire, and, unlike fictile goods, having no shrinkage or alteration of color in the making. Whatever the required size of the finished stone, it is moulded exactly to that size, with no allowance as in moulding fire-clay goods or in pattern-making for castings in iron. The heaviest blocks for works of stability, and the most elaborately ornamental capitals, tracery, or copies of statuary may be made with almost equal facility. For any purpose for which natural stone has ever been used for construction or architectural ornament, the artificial stone will fitly take its place. Mr. Fowler has used it extensively in the stations of the Metropolitan railway; Messrs. Lucas Brothers have used it with success in various works; several manufacturers at Ipswich and elsewhere have the bed-stones of their steam-engines, steam hammers, oil mills, &c., formed of the new stone. Mr. Ransome has moulded a large number of Ionic capitals for the New Zealand post office, and still more richly embellished capitals, modelled from those of the Erectheum at Athens, for public buildings at Calcutta, besides a great amount of decorative work for English architects. We understand that some thousands of Corinthian capitals of this stone are specified for the new St. Thomas's Hospital, and the architects of the Grand Hotel of New York have decided to employ it for all the decorative work of the grand court of that edifice.[1]

"While, however, the new stone affords every facility for ornamental moulding, we consider that its more important purpose is as a substitute for ordinary cut building stone, and for that employed in pilasters, win-

[1] This project has been abandoned, but the fact mentioned shows that the invention of Mr. Ransome is appreciated so far as it has become known in our country.

dow dressings, garden balustrades, &c. It is truly the stone for the million, as well as for the mullion, and ought to take the place of stucco for exterior work in our town houses. We have not heard that the workmen have set their faces against it, although an intimation of this sort would not surprise us, but we should suppose that a proper knowledge of its advantages would insure its general adoption in spite of any possible opposition of this kind. We believe it to be the fact that builders are slow to move, but there are always exceptions, and, as in other trades, great improvements like this will make way against all opposition.

"On the visit to the new works above spoken of, Mr. Dimes made an experiment upon two cubes of the new stone, each four inches square, and made only ten days before. One took forty-four and the other forty-eight tons to crush it, while a like cube of Bath stone gave way at fourteen tons. Mr. John Grant, the assistant engineer to Mr. Bazalgette, of the Metropolitan Board of Works, also made experiments on the same occasion, on the tensile strength of the stone. Specimens having a sectional area of two and a quarter inches bore, respectively, eight hundred and seventy pounds and twelve hundred pounds. These specimens had been made but five days previously.

"The new works of the Patent Concrete Stone Company have been laid out upon a large scale and admit of easy extension. They are already engaged upon a large amount and a remarkable variety of work, and it cannot be doubted that the excellence and great cheapness of their manufacture, the former now proved by nearly every test known to engineers, architects, chemists, and builders, will rapidly secure for it a vastly wider introduction than it has yet attained."

Besides the important applications of the Ransome process to the manufacture of building stone, and to the reproduction of the works of art, it has furnished a very valuable aid to mechanical industry, by providing the best material yet known for the manufacture of grindstones. The extreme hardness of the silicious cement which binds together the grains which compose this material, secures it from the rapid disintegration which takes place when steel tools are ground on the best grindstones formed from natural rock. The following interesting notice of these stones is derived from the same source to which we are indebted for the foregoing description:

"The success which has attended the application of Mr. Ransome's beautiful process to the manufacture of artificial grindstones has been so marked that there seems little doubt that the use of natural stones for grinding purposes will eventually become the exception instead ot the rule. Amongst other firms, Messrs. Bryan Donkin & Co., the well-known engineers of Bermondsey, have tried experiments which very decisively prove the advantages of the artificial over the natural stones. Messrs. Donkin were first supplied with a pair of Mr. Ransome's artificial grindstones in December last, and early in the present year they

carefully tested these stones and compared their efficiency with some Newcastle stones at their works. Both the natural and artificial stones were mounted in pairs on Muir's plan—a system in which the peripheries of the two stones of each pair rub slightly against each other, with a view of causing them to maintain an even surface—and the two sets of stones were tried under precisely the same circumstances, except that the Newcastle stones had a surface speed more than twenty per cent. greater than that of the others.

"The trials were made as follows: A bar of steel, three-fourths of an inch in diameter, was placed in an iron tube containing a spiral spring, and the combination was then arranged so that the end of the bar projecting from the one end of the tube barely touched one of the artificial stones, while the other end of the tube rested against a block of wood fixed to the grindstone frame. A piece of wood of known thickness was then introduced between the end of the tube and the fixed block, and the spiral spring, being thus compressed, forced the piece of steel against the grindstone. The same bar of steel was afterwards applied in the same way, and under precisely the same pressure, to the Newcastle stone, and the times occupied in both cases in grinding away a certain weight of steel from the bar were accurately noted.

"The results were that a quarter of an ounce of steel was ground from the bar by the artificial grindstone in *sixteen minutes*, while to remove the same quantity by the Newcastle stone occupied *eleven hours ;* and this notwithstanding that the surface speed of the latter was, as we have stated, more than twenty per cent. greater. Taking the twenty per cent. greater speed of the Newcastle stone into account, it will be seen that the eleven hours run by it were equal to thirteen and three-quarters hours at the same speed as the artificial stone, and the proportional times occupied by the two stones were thus as sixteen minutes to thirteen and three-quarters hours, or as one to fifty-two, nearly!

"Such a result as this is something more than remarkable, and it is one which would scarcely have been credited, even by those who made the experiments, if it had not been fully corroborated by subsequent experience in the working of the artificial grindstones. Since the experiments above described were tried, Messrs. Donkin have set another pair of the artificial stones to work, and these, which are now in regular use, have given even more satisfaction than those first tried. The saving in time, and consequently in labor, effected by the use of the artificial grindstones, is, in fact, so great, that Messrs. Donkin have determined to use these stones exclusively in future; and we may add that the artificial stones are so much preferred by the workmen, that those men, even, who are employed in shops at some distance from that in which the stones at present in use are situated, prefer taking the trouble to go to them to using the Newcastle stones in their own shops. In addition to their great efficiency the artificial grindstones possess the advantages of being able to be manufactured of any size, and of any degree of coarse-

ness of grain, and they can thus be specially adapted to any particular class of work, while the process of their manufacture insures their being of uniform texture throughout, and free from the flaws and hard and soft places found in natural stones. Altogether, we believe that the general adoption of the artificial grindstones is merely a matter of time."

III.—ARTIFICIAL FUEL.

AGGLOMERATED COAL.

By this term is meant the solidification of the waste of coal, the dust and minute fragments of which no use could be made, into masses capable of being handled, and which, in this form, become as valuable a combustible for every purpose as natural coal itself. Some qualities, indeed, of this artificial combustible, appear to give better results than the best coals with which they have been compared. This form of fuel was among the most interesting of the economical novelties which presented themselves in the Exposition. The machines used in the manufacture were also exhibited by several of those who presented their products. Among these there was considerable variety, but all of them appeared to be very well designed. A subject of such interest early occupied the attention of the writer; but while he was still engaged in the collection of information in regard to it, an article so full and satisfactory was published in the London Engineering, that it has seemed to be preferable to quote it entire rather than to present an original account. The writer says:

"Artificial fuels may be said to now appear for the first time in an international exhibition as a practical and accomplished fact. We have compressed coal slack and coal dust, forming a solid and easily transportable fuel, of excellent quality, produced by a simple and inexpensive process from the smallest particles of coal which have generally been considered as utterly valueless, and have formed an encumbrance rather than a source of gain to the proprietors of coal mines. This process, first long ago adopted with considerable success in England, was taken up in Belgium about five years ago, and has since then been introduced into France and Austria with perfect success. The Paris Exhibition represents this new branch of industry in its present state by samples of artificial fuel, and by models and illustrations of the different machines employed in their production.

"The process of compressing coal dust consists in mixing this material with a cementing matter, which, after being exposed to a high pressure, will effectively bind the loose particles of coal together, and form a solid block of considerable strength. With some kinds of bituminous coal it has been found that the mere application of considerable pressure at a somewhat elevated temperature is sufficient for making the small particles adhere to each other, so as to prevent them from falling into dust upon the fire-grate, and to make them burn like solid blocks of coal or of wood.

The fuel compressed in this manner is, however, rarely capable of standing the rough usage of transportation, and it is, therefore, only in special localities that it can be applied, while those kinds of artificial fuel which are now an article of commerce on the continent are made by the application of a cement. The first cement ever applied, we believe, was clay; but this material being incombustible, and producing a very large quantity of ashes in burning, was soon discarded. The application of coal tar was then resorted to, and gave very good results. The different kinds of coal required more or less of the cementing material according to their own more or less bituminous character, and according to the higher or lower pressure to which they are exposed. Coal tar, as a cement, has, however, in the most recent practice been superseded by another organic substance obtained as a residue in the manufacture of starch, and practically almost valueless for other purposes. This substance can be employed in quantities not exceeding one per cent. of that of the coal dust to be compressed with it; it leaves no ashes in burning, and, what is still more important as compared with the ready liquidity of coal tar, it does not melt at a high temperature, so that its binding effect is not lessened when exposed to the heat of the fire. The Paris Exhibition contains compressed fuel from several French collieries, among which the Mines de Grande Combe, the Compagnie Anonyme des Houillères de la Chazotte, near St. Etienne, and Mr. Felix Dehaynin, of Paris, are the most important, the latter exhibitor having one of his establishments in Marcinelle, in Belgium. From Austria the Northern Railway Company, who own extensive coal pits at Ostrau, in Moravia, have also sent some very good samples of their artificial fuel. The compressing machines are of very different construction, but that most approved of seems to be the machine invented by Mr. Evrard, the engineer of the company of Chazotte, and another constructed by Mr. Mazeline. The material in this machine is forced within cylindrical pipes of cast iron by the resistance offered to its passage through the pipe, and caused by the friction of the material against the sides of the pipe. The compressed fuel passes out of these cast-iron pipes, as a continuous cylindrical bar, which is broken in suitable lengths, and then sold much in the form of round logs of wood. Mr. Mazeline's machine, exhibited both in original and in a model, produces bricks of prismatic form. It consists of a mixing apparatus, which feeds the material into a kind of brick-making machine, having about twelve square moulds arranged in a circular frame, which has a rotating movement. Each die is worked by a square piston projecting into it from the bottom, and acted upon by an inclined plane which presses the pistons upward during the revolution of the circular frame, so that each brick is completed and delivered by the respective mould, making one complete turn round the central axis of the machine. These bricks have the advantage of being more easily stored than those of cylindrical form, but the machines do not produce the same quantity as those of equal cost on Mr. Evrard's plan. The character and qualities of these kinds of compressed fuel which

on the continent have the name of *briquettes* or *charbon aggloméré*, (coal bricks,) must, of course, depend upon the nature of the original coal from which they are produced. The Belgian coal, and that of St. Etienne, which always requires washing, on account of the pyrites and other impurities which it contains, must go through this process before being compressed; the coal from screenings and dust, from Ostrau, on the other hand, is so pure as to require only cementing together to make an excellent fuel. Mr. Dehaynin states that his machine, being a modification of Mr. Evrard's construction, produces ten tons of fuel per hour, with a motive power of eighty horses. The whole machine weighs about sixty-five tons, with all its accessories and gearing, including the steam-engine. The coal bricks are slightly heavier than natural coal, and their calorific effect has been found fully equal, and, in some cases, even superior, to the latter. The process of washing removes about five per cent. of the weight of the coal dust, representing incombustible impurities, and the compressed fuel leaves only six to seven per cent. of ashes. Mr. Dehaynin's works produced one hundred and seventy-five thousand tons of this fuel last year, which has been sold to the different railway companies and the navy, besides a great quantity for household purposes, for all of which applications the briquettes are preferable to natural coal on account of its greater regularity of form, greater cohesion, and consequently improved cleanliness in firing, besides also for its high heating effect. The compressed fuel of Chazotte leaves only four or five per cent. of ashes. It is made from anthracite coal, containing eighty-one per cent. of uncombined carbon, 16.5 per cent. of hydrocarbon, and 2.5 per cent. of ashes. Some experiments made by the Messageries Impériales, and by other parties, have shown a superiority of this fuel over the best coal from Cardiff, amounting to ten per cent., weight for weight. The Northern Railway of Austria has a production of fifteen thousand tons per annum. The *briquettes* evaporate 7.1 to 7.2 pounds of water per pound of fuel in regular practice with locomotives for passenger trains, which use this fuel in preference to coal. The large coal from the same mines has about the same heating effect, while the coal slack in its natural state could not be considered to have more than five-eighths of this heating effect, even with careful firing and a suitable grate. The coal bricks of the Northern Railway are prismatic, nine inches long, five inches wide, and four and a quarter inches thick; they weigh eight pounds each, and are made with a cement consisting of the refuse of the starch works. They are compressed in a damp state, and afterwards dried in a kiln heated overhead by a current of hot air. The time for drying is about three hours. The form of these bricks makes them extremely convenient for all practical operations. Their weight being always constant, it requires only to count the number of bricks for delivering the exact quantity of fuel required, except, of course, to purchasers. The stowage is very much facilitated, and the loss from coal crumbling into dust is considerably lessened. The prime cost of this material, taking the coal dust at its selling price at the pit's

mouth, is considerably below that of the solid coal drawn from the same pits, while it is in many instances effective in lessening the working expenses of mining operations, thereby reducing the prime cost of the coal itself. There can be no doubt that this valuable process will soon find its way into the collieries of England, where its beneficial effects will be incalculable. Considering the enormous quantities of material, now next to valueless for all purposes of industry, which may be converted into the most excellent fuel by such simple means, and at a moderate cost, the process of compressing fuel appears to be one of the most important of modern inventions, and one of the greatest steps in advance represented by the present Exhibition. It is a practical and commercial reality, but still in the first stages of its infancy. Its introduction into the English coal districts can hardly be postponed any longer, and, if once in operation on that enormous scale which it is capable of acquiring in the British collieries, will form one of the greatest sources of wealth ever known anywhere."

Important as the introduction of this manufacture into the coal regions of England may be to that country, it can hardly be less so to the United States. To save the immense waste which is continually going on wherever coal is handled, whether at the mines, or in transportation, or in the hands of the venders on the large scale, would not only have the effect materially to add to the comfort of multitudes who now suffer from the high prices of fuel, but would also powerfully contribute to the economy of every industry.

IV.—MATERIAL AND MANUFACTURE OF PAPER.

VARIETY OF SPECIMENS AND MATERIAL.

The variety of the specimens of manufactured paper exhibited was almost endless, and the beauty of the superior qualities presented by nearly every country of Europe, but especially by France, England, Austria and Prussia, was all that could be desired. In regard to processes of manufacture, nothing was presented of especial novelty. Belgium only exhibited a machine for the continuous manufacture, which, however, was not put into operation. It was exposed by Messrs. Dautrebande & Thiry, of Huy, and as a specimen of superior workmanship was eminently creditable to its constructors.

What was chiefly interesting in connection with this important industry was the display of papers manufactured more or less entirely of materials other than cotton or linen rags. The immensely increased consumption of paper of all descriptions in recent years, and the steadily increasing demand, a necessary consequence of the progress of enlightenment, the growth of commerce, the improvement of the arts, and the enlargement of the operations of industry in all its departments throughout the world, have rendered it a matter of the greatest urgency to provide some new and inexpensive means of maintaining the supply.

Cellulose, the essential constituent of paper, is found in sufficient abundance throughout the vegetable kingdom; but the number of plants from which it can be separated in condition suitable to be manufactured into paper is comparatively small. In order to fulfil this purpose, it must be capable of forming strongly coherent films, by the interlacing and felting together of the fibres of which it is composed. These fibres must, therefore, have a certain length, and the processes by which they are separated from the substances with which they are found naturally associated, and which impair their usefulness for this manufacture, must not be such as to injure their tenacity. In certain plants, the fibres of the cellulose are conspicuous and separable without much difficulty. The various descriptions of cotton furnish it almost pure, or contaminated only by a little oil. In flax and hemp it is encrusted with other substances, organic and mineral, more or less difficult to be disposed of, but which when removed leave it in long and tenacious bundles of fibres. In jute, China-grass, the American aloe, straw, spartero, and the grasses generally, it is found similarly combined and is separated still less easily. It forms a large portion of the solid mass of all descriptions of wood, from which it may be obtained by processes either mechanical or chemical, or by both combined; but it is generally then too short in fibre to be available in the manufacture of paper without an admixture of a large proportion of cotton or linen rags. Several of the softer woods have, however, been largely employed in the preparation of paper pulp, among which may be mentioned poplar, elm, fir, beech, linden, and birch. The most beautiful papers exhibited were from Japan, and were manufactured from the bark of the so called paper tree, the *Broussonetia papyrifera.*

WOOD PULP—VOELTER'S MACHINE.

Wood pulp has been very largely introduced into the paper manufacture, both in Europe and in our own country, and it is prepared at present on a large scale by both the processes above mentioned. There are now in Germany more than thirty establishments engaged in its preparation by the mechanical method, in all of which a machine is used which was patented some years ago by Henry Voelter, of Wurtemberg. One of these machines, exhibited by Messrs. Decker, Brothers & Co., of Canstatt, was in constant operation during the Exposition, in the Wurtemberg annex.

This machine, which is of very large dimensions, presents the appearance of a succession of tanks at different levels, like a flight of steps. At the summit is what is called the *defibrer*, a kind of rasping mill, in which the fibres of the wood are torn off and separated by the action of a coarse cylindrical stone against which it is pressed, and which is kept in constant revolution. In the machine exhibited, this stone had a diameter of about four feet and a thickness of sixteen inches, and it revolved one hundred and fifty times per minute. This is nearly the largest

model constructed, though there are several smaller. It is capable of producing daily (running twenty-four hours) about half a ton of wood pulp "air-dry;" by which, however, it is to be understood that the substance still contains about fifty per cent. of water, which is necessary to preserve it in good condition during transportation. A force of five horse-power per hundred weight per day is expended in driving the machine. The amount of pulp delivered is equal in weight to half the raw material consumed. Two or three attendants only being necessary, it is easy to make an estimate of the probable expense of running such a machine in a given locality.

The wood is prepared for the machine, by being sawed into lengths of fifteen or sixteen inches, after having been first deprived of its bark and reduced to the diameter of about five or six inches. In case there are knots, these are removed by boring. If they cannot be se removed the wood is rejected. Each billet is then placed in a holder adapted to apply it firmly to the stone. Six such holders were attached to the machine exhibited, and were all in use at once, occupying about one quarter of a circumference. The pressure is applied by means of a screw behind each holder, which is very gradually driven by the machine itself. A single band acts at once upon all these screws by intermediate mechanism, and in case the several billets are not ground off with equal rapidity, the proper adjustment effects itself by the slipping of the band.

The stone is enclosed in an iron box, and water flowing in constantly at the top removes the disintegrated fibres, as fast as they are produced. From the mill the comminuted mass is carried along, in suspension in water, into the first tank, in which there is a cylindrical strainer, formed of very coarse wire gauze, constantly in revolution. The discharge from this tank, which, to prevent overflow, must be equal to the supply, takes place from the axis of this strainer, which is made large and tubular for the purpose. The flow is, therefore, from the exterior to the interior, through the meshes of the strainer, and the slivers and coarser fragments of the wood, being thus prevented from passing, are from time to time removed. The water, with the available portion of the fibre, is discharged through a lateral duct into a second tank at a lower level, where it undergoes a straining similar to the preceding, but through a gauze considerably finer. The process is repeated until the pulp has undergone four successive strainings, when the material is passed into a fifth tank in which the strainer is so fine as to allow the water only to pass. Between the second and third of these straining tanks, there is an auxiliary apparatus which must not be overlooked. It is called a refiner, and resembles an ordinary grist-mill. Into this are conveyed the coarser fragments detained by the second drum, and these here undergo a second grinding. The three cylinder strainers below the refiner constitute what is called the sorting apparatus, and furnish pulp of successive degrees of fineness. The manufacturers state that they have furnished, up to 1867, ninety of these machines to different countries, one of which was sent to America, (Canada.)

WOODS BEST ADAPTED TO THE PRODUCTION OF PULP.

The woods which furnish the best fibre, that is, the fibre of greatest felting power, are pine and fir; but the poplar and linden furnish the whitest pulp. The fibre of the birch and beach is shorter than that of either of the foregoing, but is much in use in Belgium and France. No wood pulp yet manufactured, however, will suffice to prepare a paper of good quality by itself. Its fibres are in all cases excessively short when compared with those of linen or cotton rags. If a good piece of cotton paper be softened in water and carefully pulled to pieces by means of needle points, its separate fibres may be distinguished by the naked eye, and will be found sometimes to exceed a tenth of an inch in length. Those of wood pulp are nearly undistinguishable without a magnifier, and will not average a fifth part of the same length. A certain proportion of this material may, however, be employed, without very sensibly diminishing the durability, which is so important a property of paper; but this proportion can hardly exceed one-fifth part. For papers of secondary quality, as for newspapers, posters, wall paper, &c., fifty per cent. is sometimes employed, though not with advantage, as is evident in the examples furnished in some of our daily journals. In the rougher wrapping paper a still larger proportion is introduced, the material being also of a coarser character.

CHEMICAL TREATMENT OF MATERIALS FOR PAPER.

It is, however, by chemical processes, or by processes mainly chemical, that substitutes for rags in the manufacture of paper are at present principally prepared; and though wood is the material employed in some of these processes, they embrace also straw, grasses, and other vegetable substances. One of these processes consists in subjecting the substances operated on, after they have been reduced to proper dimensions, to the action of strong solutions of the fixed alkalies, under pressure and at high temperatures, (300° F,) and subsequently bleaching by chloride of lime. After the operation, the alkali (potash or soda) may be recovered with little loss.

Another mode of treatment is to subject the material first to the action of strong hydrochloric acid, to which has been added a small quantity of nitric, continuing the immersion for a number of hours. Or the effect desired may be obtained by means of a very dilute solution of the same acids, provided the temperature be elevated to boiling. The substance, after this digestion, is washed and drained, and finally ground to a pulp. It is then digested in a solution of ammonia, and afterwards bleached by means of chloride of lime. Numerous establishments in France and other countries of Europe prepare paper pulp by these processes, to the extent of from one to ten tons a day. The superiority of the pulp thus prepared over that prepared by mechanical means is very considerable, and results from the fact that the fibre is less broken, and is probably

much more thoroughly freed from the indurating substances which diminish its flexibility and increase its brittleness. The chemically prepared pulp can be used to the extent of four-fifths, while that prepared mechanically can at best be used in no greater proportion than thirty per cent., unless for papers of avowedly inferior quality.

BACHET AND MACHARD'S PROCESS.

To the chemical processes above mentioned may be added another' invented by Messrs. Bachet and Machard, and described by Mr. Payen, in his jury report, which proposes to convert a part of the substances incrusting the fibres of wood first into grape sugar, and then into alcohol, while transforming the fibre itself, at the same time, into a pulp suitable for the manufacture of paper. The process, on a large scale, is conducted as follows: Into a large vessel, containing more than two thousand gallons of water and one thousand six hundred pounds of hydrochloric acid, there are introduced two tons of fir wood in the form of billets. By means of a current of steam the water is maintained in ebullition for twelve hours, after which the acid solution is withdrawn and nearly saturated with carbonate of lime. Yeast is added, and the temperature maintained at 75° to 80° F. Subsequent distillation yields a considerable quantity of alcohol. The wood is then crushed after washing, and the coarser parts are separated by levigation. A brown pulp is left which is very suitable for heavy wrapping paper. A lighter paper of similar kind is obtained by compressing the brown paste with rollers, and rolling the boards thus produced around mandrels, which are placed upright in a tight vessel to which chlorine gas is supplied. The boards being still charged with six per cent. of water, absorb more than a cubic foot of gas to the pound of the solid, supposed dry. The color is then found to have passed from a brown to a reddish tint, and the paper formed of the pulp in this condition is very handsome. In order to obtain a perfect white, the pulp, in the condition to which it is brought by the process just described, is first digested three several times in lime water, and then treated with ten per cent. of carbonate of soda at a temperature near the boiling point. It is then very thoroughly washed and afterward subjected to the action of chloride of lime.

The wood, as reduced to billets before the chemical operation commences, is in weight about four-fifths of the original raw material. The weight of the brown or red pulp obtained in the first process is about one-fourth that of the prepared wood; and in the final purification, for the purpose of obtaining a fine white paste, there is a loss of thirty per cent. The total product of paper of this quality is, therefore, about one-sixth part of the prepared wood, or one-seventh of the raw material in weight. The net cost is a little over fifty francs the hundred kilograms, or one hundred dollars a ton. In general, it is stated by Mr. Payen that the chemically prepared pulps cost less than pulp from rags

by one-half. At present, according to the same authority, the annual production of the material of paper directly from various vegetable sources, amounts to one-tenth of the whole consumption. This fraction is doubtless destined to be rapidly increased.

V.—EXTRACTION OF OILS BY MEANS OF SULPHIDE OF CARBON.

EXHIBITION BY SCHLINCK AND RUTSCH.

An important and interesting industry, which has sprung up within a comparatively recent period, was illustrated at the Exposition in a collection exhibited by Messrs. Schlinck and Rutsch, of Ludwigshafen, Bavaria, of a variety of vegetable oils separated from oleaginous seeds and nuts without pressure, by solution in the bisulphide of carbon. In this process the seeds are in the first instance crushed, ground, or otherwise reduced to a fragmentary or pasty condition. They are then immersed in the solvent, which thoroughly extracts the oil and resin which they contain, but leaves the substance otherwise unaltered. The volatility of the sulphide is so great that it is easily distilled off without loss, leaving the oil, like the raw oils extracted by pressure, contaminated to some degree with resinous and coloring matters, which are removed by a second process of refining.

REMOVAL OF OIL FROM WOOL.

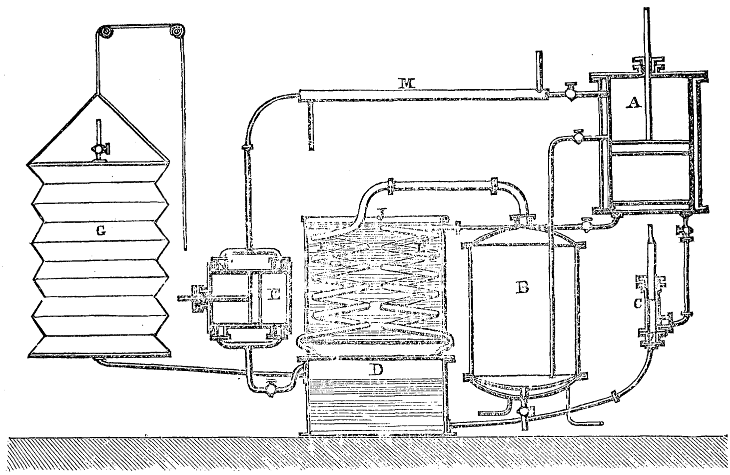
This method of separating oils, fats, and resins from the solid substances with which they are mechanically combined, has been heretofore in use for the purpose of removing the animal oil from wool, and also for the purpose of cleansing and restoring to use those portions of fleeces which have been made unavailable by marking the sheep with tar or other resinous material. It has been employed before for the same purposes to which the exhibitors above named have applied it, but hitherto only as supplementing the mechanical process of separating oil from seeds or olives by operating on the solidified residua which are known under the name of oil-cake, *marc*, &c. At the International Exposition of 1862, Mr. E. Deiss, of Paris, exhibited specimens of superior oils extracted in this manner from the *marc* of olives. Mr. Payen, in his report on that Exposition, has described the process as originally applied successfully to the cleansing of wool by Mr. Moison, of Mouy, Department of the Oise in France; and as this process illustrates the principle of the operation in other cases, though the details may be different, it is here given in abridged form from that report.

It is to be observed in the first place that the case of wool presents a difficulty which is not encountered when the object in view is only to obtain the oil which the substance operated on happens to contain.

The wool itself is in this case the important material, and the value of the oil separated from it is a trifle of secondary consequence. In the

original experiments the point of difficulty in the practical problem was found to be how to expel the bisulphide from the wool after the operation of solution had been completed, without injury to the wool itself. Too great heat, in whatever manner applied, was found to have the effect of hardening the fibres, making them cohere, and giving them a tinge of a yellowish brown color, which was variable in intensity according as the material had been a longer or shorter time in contact with the fatty matters removed. The mere volatilization of the bisulphide was effected without difficulty. It sufficed for this to introduce into the vessel containing the material to be operated on, either boiling water or steam; but the injurious effects above described invariably followed. Mr. Moison discovered at length that with proper arrangements a current of air heated to a temperature considerably below that of boiling water, 70° or 80° C.=160° to 175° F., would remove the liquid entirely, and leave the fibre of the wool wholly uninjured. The apparatus employed in conducting this process is shown in the Fig. 80 annexed. The wool to be subjected to the operation is introduced into a cast-iron

Fig. 80.



Moison's apparatus for removing oil from wool.

cylinder, A, surrounded by a jacket into which steam may be conducted when it is necessary to raise the temperature. One hundred kilograms, say two hundred and fourteen pounds, of wool are placed in this cylinder at once. There is within the cylinder a false bottom perforated with numerous holes, with a small free space beneath it. Upon the top of the wool is placed a circular follower or compresser, fitting the interior of the cylinder, and perforated also with holes like the false bottom. Three rods connected with this follower pass through stuffing boxes in the lid, and may be driven downward by means of fixed screw-nuts, the rods having screw-threads cut upon their prolongations above the cylinder. The object of this arrangement is to compress the wool to a cer-

tain extent, since the success of the operation is always most satisfactory when the mass of the material is reduced in advance to about one-half its original volume.

The lid is secured air-tight by means of bolts and screws, a leaden washer being introduced into the joint. Matters being thus prepared, liquid bisulphide of carbon is thrown into the cylinder beneath the false bottom by means of a forcing pump, C, which draws the liquid from a reservoir, D. This liquid rises through the perforations and completely immerses the confined wool, reaching at length a point above the perforated follower, where it finds a lateral overflow tube. This conducts it into the still or alembic B. Here the bisulphide is volatilized by the heat of steam, which is introduced into the double bottom of the vessel and also into the midst of the liquid masses itself by means of a spiral tube within the alembic, not shown in the figure. When the process is complete and the oil in the alembic is entirely free from the bisulphide, the stop-cock beneath permits to withdraw the product. Before this is done, however, steam is introduced into the mass of the impure oil by means of a second spiral tube, which is also not shown, and which is perforated with numerous holes. The design and the effect of this part of the process is to remove the last traces of the solvent.

The vapor of the bisulphide is conducted from the alembic to the refrigerator J, where it is condensed in the spiral L, and is finally returned to the reservoir D.

There is a stop-cock in the overflow tube which leads from A to B, through which may be withdrawn at any time a few drops of the liquid passing through the tube. When the specimen thus withdrawn, on evaporation upon glass, leaves no trace of oil or other residuum, the operation of the pump C, may be suspended. For a short distance this tube is of glass, for the purpose of enabling the attendant to observe the color of the passing liquid.

The process of solution being complete, communication with C is cut off by means of a stop-cock, and two other stop-cocks are opened. One of these permits the liquid in A to descend through the spiral H to the reservoir D. The other allows air to be introduced into the upper part of A by means of the double-acting piston-blower E. The air, as the figure shows, may be drawn from D; but the stop-cock beneath E is a three-way cock, and it allows the supply to be taken also from the atmosphere. In passing from E to A, the air is conducted through the jacketed tube M, and steam is introduced into the jacket to heat it to a degree sufficient to complete the volatilization of the bisulphide in A. But the first part of this operation, which consists in the mechanical expulsion of the bulk of the liquid in A, may be conducted without heat. The cock in the tube leading from A to H is a three-way cock, as well as that beneath E. At the close of the operation, the air blown through may be discharged into the atmosphere without passing through H. In that case it is conducted, by a long tube not shown, out of the building,

in order that any disagreeable odor which may accompany it may not annoy the attendants. The two spiral tubes, H and L, pass out of the refrigerator J, before entering the reservoir D. At these points they are provided with small stop-cocks, not shown, to permit the examination of the substances passing through them. Into each of these tubes, also, as into the one leading from A to the alembic, is introduced a short glass tube as a part of its length, so that the interior of any one of them may be inspected.

There remains one additional portion of the apparatus to be mentioned, which is the gasometer G. While the process is proceeding without any communication with the atmosphere, the volume of the confined air may vary with the temperature, or with the compression in A, and the volatilization of the bisulphide will also add something to the bulk of the aeriform mass. The gasometer, which may be, as represented, of the bellows form, or may be the ordinary bell and cistern, will serve to keep the capacity of the apparatus properly adjusted to the varying volume of the contents.

The boiling point of the bisulphide of carbon is 48° C = 118° F. If the air introduced into A is therefore heated to 70° or 80° C, the volatilization will be rapid; and this temperature does not affect injuriously either the structure or the color of the wool.

A considerable economical advantage is obtained by this process, in the mere recovery to use of considerable quantities of wool which have been ruined by the pitch employed in marking. The animal oil separated has also some value.

But the same process employed to dissolve the oils contained in the strippings of machine cards in factories, which amounts to one-third of the entire weight, is the source of a considerable saving. This oil is what has been added in previous stages of the manufacture, and after being thus recovered it may be used again.

The wool which has been freed from oil by the process above described, on being subjected to the operation of the picking and beating machines preliminary to carding, yields a large proportion of fine fragments, or what may be called wool dust; said by Mr. Payen to amount to forty-two per cent. of the total weight. This is valuable as a fertilizer in agriculture, and is so turned to account. Under former modes of treatment, it was a total loss.

But the application of the process above described has been more recently extended to a great variety of purposes. Thus, when the pitchy glycerine deposits, formed during the saponification with sulphuric acid —which is made a preliminary to the distillation of fatty bodies—are acted upon by the bisulphide, they yield a considerable quantity of stearine, amounting to eighteen or twenty per cent. of their weight. The waste grease of the kitchen, the exudations which take place from the axles of vehicles or the journal boxes of machinery, and all similar forms of oils and fats, contaminated by impurities which, though they form but a small

part of the weight, destroy entirely the value, are completely restored by this process, which recovers the valuable portion, and leaves the impurities behind. Rags, swabs, and fibrous materials of any kind, which have been employed in cleaning machinery or the parts of locomotives which it is necessary to oil, soon become saturated to such an extent that they are commonly thrown aside as useless; but these give up a large amount of oil to the solvent employed in the new process, which is in itself a gain; and the process also gives to the rags themselves a value which they had lost, since it permits them to be re-employed for the same purposes as before, or to be used in the manufacture of paper. In the direct extraction of wax by pressure, there is left in the solid residue a proportion of twenty per cent. of valuable material which may be recovered by solution in bisulphide of carbon. This does not render the residue unfit for use as a fertilizer, (the purpose to which it is commonly applied,) but rather improves it. Sawdust which has been used for the filtration of oils purified by sulphuric acid, yields to this process fifteen to eighteen per cent. of its weight. The acid impurities separated from oils in the process of purification by agitation with a small proportion of sulphuric acid, furnish by proper treatment with bisulphide of carbon half their weight of pure oil. Bones of animals obtained from the shambles, from the streets, from kitchens, and from various other sources, are used to the extent of many millions of pounds annually in every country, for the manufactures of glue and of animal charcoal. These are usually to some extent exhausted of their oils by boiling, before being used in the manufactures for which they are intended; but the boiling separates only six or seven per cent., while the bisulphide process extracts ten or eleven. The oil-cakes which are formed in the mechanical process of the expression of oils from seeds of various kinds furnish, as mentioned above, a large proportion of oil which the press has left behind. These cakes are sometimes broken up, reduced to powder, and pressed again with the aid of heat. But the labor of the second compression is greater than that of the first, and the product is less, while it still leaves the residue unexhausted. The cakes have a value as food for animals. It was at first supposed that the complete removal of their oil would injure them for this use, but experience has shown this impression to be an error. It is asserted by Messrs. Schlinck and Rutsch, the exhibitors mentioned above, to have been fully proved by experiments on a large scale, already made, that in regard to the production of milk, butter, and flesh, the residua from which the oil has been thoroughly extracted are far superior to the pressed cakes, and that they retain their good qualities as food for animals, though kept long in store. The compacted masses left in the extraction of tallow or lard by pressure, furnish twenty per cent. additional, when treated with bisulphide of carbon. The residue from the compression of cacao gives a similar increase of product on similar treatment. Finally, the *marc* of olives, as exemplified in the exposition of Mr. Deiss, furnishes quantities of excellent oil, which the press fails to separate.

The peculiarity of the industry of Messrs. Schlinck and Rutsch is, that they do not take the trouble to use the compression process at all in their treatment of the oleaginous seeds from which their oils are obtained; that is to say, they do not first extract a portion of the oil by pressure, and then subject the residuum to the action of the solvent, as has been done by others before them. It appears to them that if the bisulphide is capable of supplementing profitably the work of the press, it can perhaps perform the whole work more profitably still. Their experience demonstrates the truth of this supposition. They show specimens of oil before and after refining, obtained from American, Egyptian, and Italian cotton seed, from German flax seed, from rape seed, from poppy seed, from sesame, from Russian sun-flower seed, and from the nuts of the beech. In appearance their refined oils are all that could be desired—being colorless and limpid as water. In the refining of their oils, they practice a method of their own for which they claim peculiar merit, without stating what the method is. They state, however, what it is not, affirming that it involves the use of neither acids nor water—reagents which, as they assert, are indispensable in the refining of any oil extracted by pressure. For this reason they further claim a special superiority for their drying and their lubricating oils; since the absence of water causes the drying oils to become rapidly inspissated on exposure, while the lubricating oils are entirely free from any trace of a reagent capable of attacking metals. These claims are given as stated, no opportunity having presented itself for experimentally testing their validity. If they are well-founded, this process possesses the double value of securing in an important branch of industry a product which is at the same time more abundant in quantity and better in quality than it has been heretofore possible to obtain.

VI.—ROBERT'S DIFFUSION PROCESS FOR SUGAR.

Among the improved industrial processes which have recently originated in Europe, but have not as yet come into general use, there is one having considerable interest for our own country, of which the object is to secure a more effectual extraction of saccharine matter from beet-root and the sugar-cane than has been found hitherto practicable. This process, called Robert's diffusion process, was invented a few years ago in Austria, and it has been more recently patented in England by Mr. Minchin, the managing partner of the Aska Sugar Works, in the East Indies. Though it was represented at the Exposition, it escaped the notice of the present writer, who failed, therefore, to become personally acquainted with it; but the reports which have appeared of the experiments made with it, and their encouraging results, give it an importance which justifies the introduction here of the following succinct account of its history and present promise, derived from the London Engineering:

"We have repeatedly drawn the attention of our readers to the interesting and highly scientific process for extracting sugar from the cells of

plants, invented by Mr. Robert, in Austria, and patented in this country by Mr. F. J. V. Minchin, the managing partner of the Aska Sugar Works, in the East Indies. This process has been brought before the public at the Paris Exhibition in the form of a collection of specimens illustrating the entire manipulation as applied to sugar-cane, and the results obtained in actual, though not as yet in completely organized, practice. The collection of Mr. Minchin's samples is placed in the Indian department close to the other exhibits of sugar from India, with which it contrasts very remarkably in many respects. We may repeat here wherein Mr. Robert's process consists. The plants are cut up into thin square slices by means of very sharp and clean cutters so as not to destroy the cellular structure of the plant, but only to produce a large surface on which the liquids employed for extraction can act. The slices are filled into large vessels and covered with water at an elevated temperature, the precise temperature used varying with the circumstances of the case. The water in contact with the slices of the beet-root or cane extracts from the cells of the plant a certain proportion of sugar by the natural and spontaneous process of endosmosis and exosmosis—a process which is known to take place with all organic membranous and cellular structures, and which consists in an exchange of all liquids placed in contact with the membrane at opposite sides. The contents of an organic cell surrounded by water are in this manner mixed or exchanged with the outer liquid, so that a cell containing a solution of sugar, and surrounded by pure water, will after a certain time contain a weaker saccharine solution, while the water outside will have taken up some of the sugar contained in the cell. If carried to the extreme, the liquids will exchange contents until the same mixture or solution will exist both inside the cell and outside.

"Taking advantage of this property of organic substances, Mr. Robert combines a series of several vessels all filled with beet-root or sugar-cane slices, and passes water through them in a systematic order and succession. The fresh water, if passed over fresh cane, would be capable of extracting one-half of the contents of the juice from the plant, and the second half could be further reduced by another quantity of fresh water to one-half of its amount, while the solution containing the first half is capable of taking up another proportionate part of sugar from fresh cane. The order followed by Mr. Robert is therefore to let the most concentrated solutions pass over the fresh cane, and to pass weaker and weaker solutions over the plants as their contents of sugar become more and more reduced, so that the fresh water comes first into contact with the slices which have been longer under treatment, and are consequently very poor in sugar, and afterwards it passes in succession over slices containing more and more sugar, until it at last comes upon fresh cane, and attains the highest degree of concentration which the process is capable of affording. A number of such vessels combined in this manner, and working in rotation so as to make the process con-

tinuous, is called a battery; and there are, as a rule, six or eight vessels combined into one such battery for diffusion. For the manufacture of beet-root sugar, Mr. Robert's process has now been in operation for about four years, and there are about thirty factories now using this system in Germany, Austria, and in Russia, with the most complete commercial success. There are some other works of the kind now in course of construction in Belgium, and others are about to be established in France very shortly.

"The success of Mr. Robert's process with beet-root sugar was, however, not sufficient to prove its applicability to the extraction of sugar from cane. This has now been established by Mr. Minchin. The Aska Works have produced about sixty tons of sugar from fresh sugar-cane by the diffusion process. Mr. Minchin started his works in March last and commenced operations with four machines for cutting the cane into slices, which had been sent to India from Austria, these machines being the manufacture of Messrs. Wannick & Jellinck, engineers of Brünn. These four machines were driven by an engine of twelve nominal horse-power; but there was a surplus of power under these circumstances, as the actual requirements of these machines scarcely exceeds one horse-power each. The slices produced by the machines were removed by an Archimedian screw moving in a trough, and they were delivered to an elevator strap which lifted them up to the top of the diffusion vessels. There they were filled into a wagon constructed for enabling the attendant to weigh the quantities of sugar-cane used, and from the wagon the material was discharged into the vessels in proper rotation. The vessels, sixteen in number, and arranged in two sets of eight as two complete batteries, are made of wood, in the shape of large casks or vats, each capable of holding two and a half tons of cut cane and about the same weight of water. There is an addition of about fifteen pounds of slacked lime made to the water, in order to neutralize the acid contained in the juice of the sugar-cane. The temperature at which the diffusion was carried out at Aska was 155° to 165° F, the fresh cane being warmed by steam before the liquid was run over it, so as to prevent the mixture from cooling down too much. The time allowed for diffusion was forty to fifty-five minutes, the same time being required for filling one of the vessels with fresh cane; but it is the intention of Mr. Minchin to reduce the time of diffusion in future campaigns very considerably. The diffusion was found to be practically complete with five vessels; *i. e.*, there was so little sugar left in the cane slices after having been treated in this manner with five successive charges of liquid, that the process was allowed to stop there. The collection of samples brought to the Exhibition by Mr. Minchin contains some sugar-cane cut into slices for diffusion by the machinery at work in Aska. The cane contained about ninety per cent. of juice when fresh, and this juice has a density of about 15° on an average. The diffusion liquid produced from this cane by the new process showed an average density of 14°, proving how near the concen-

tration of the diffusion liquid can be brought to that of the natural juice contained in the plant itself. The notion that the diffusion process requires the evaporation of weaker solutions of sugar than are obtained by the ordinary mode of extraction is, therefore, proved to be correct only in theory, since the difference in practice is so small that the results are not affected by it. There have been also some comparative analyses made both of the contents of the cane juice when extracted by mechanical pressure and of the diffusion liquid obtained from the same kind of cane. These trials were conducted very carefully, and the specimens of both modes of extraction were taken from the same lots of plants, so as to avoid any accidental sources of error. The juice extracted from the cane by pressure was found to contain 0.62 per cent. of foreign matter or impurities, while that obtained by diffusion had only 0.43 per cent. of such substances. The nature of these impurities in the two kinds of juice produced by the two modes of extraction is one of the most important points in favor of the diffusion process. The cellular structure of the plants being preserved by this mode of extraction, it follows that the nitrogenous organic substances, which are not sufficiently soluble in water to be drawn out by diffusion, are left within the cells, and remain in the trash, so that the diffusion juice is much purer, and the raw sugar produced from it perfectly clean and white. This fact has been fully established by the products of Mr. Minchin's first campaign. The raw sugar produced at Aska, and now exhibited at Paris, is of a surprising purity and beauty. It is placed close to some specimens of refined sugar from several other Indian sugar factories, and it surpasses even these refined sugars in beauty of color and in the transparency of the crystals. The analysis of this raw sugar made by diffusion gives 96.9 per cent. of sugar, 2.94 per cent. of water, and 0.16 per cent. of foreign substances. Mr. Minchin's exhibition contains samples of the different kinds of sugar obtained from his diffusion liquids by the successive boilings; and the analysis of each specimen, which is attached to the corresponding sample, shows an equal degree of relative purity as compared with the analogous products of the usual process of extraction by mills. This part of Mr. Minchin's exhibition is devoted to the question of quality as regards the products of the diffusion process, and in regard to this point the superiority of this new mode of extraction seems to be established without further doubt. The other specimens shown by Mr. Minchin refer to the other equally important point, viz: the quantitative results, or the economy of the diffusion process. The economy in first outlay for machinery and plant of course requires no illustration. Perhaps the whole plant for the diffusion process may be erected in any one of our colonies for the same sum of money which the making and transporting of the base plate of a sugar-mill for an equal production would require. The relative economy of the other manipulation may be gathered from the description of the mode of working, and it is of less importance. The main point in question, and the only one about which doubts were

entertained, is the quantity of sugar which can be extracted from the cane, and ultimately utilized or 'bagged' as crystallized sugar. On looking to this point, we find in the Exhibition a sample of the cane-trash after extraction, and we find the analysis of its contents given by the chemist of the Aska Works. We also learn that Mr. Minchin keeps a quantity of similar cane-trash at the disposal of any chemist who desires to verify the analysis. The diffusion-trash varies in its contents between 0.112 and 0.49 per cent. of sugar, showing that the extraction by diffusion goes much further, and is much more complete, than any other method now in practice. Mr. Minchin has further established this fact by making diffusion sugar from the cane-trash left by the ordinary mode of extraction by sugar-mills. A sample of such sugar is exhibited at Paris, and it shows that the diffusion process may be effectively commenced when the ordinary process finds its limits from want of efficiency. By all this it may be considered as an established fact that the diffusion process is applicable to sugar-cane, and that its advantages, both as regards quality of the product and economy of manufacture, are very considerable. Exact figures and percentages of the relative quantities of sugar made from a given quantity of cane on a large scale have not as yet been arrived at by Mr. Minchin. The Aska factory was not originally laid out for the manufacture of raw sugar, but simply as a refinery, and sufficient means for evaporating the large quantities of diffusion juice made in this season were therefore not at Mr. Minchin's command. It was thus found necessary to use only a part of the liquid for sugar-making, and to utilize the rest for the manufacture of rum and other articles. It will therefore require another season to collect reliable data of the relative yield of sugar to be obtained from cane by the diffusion process. Even without these precise statistical figures, the advantages of the process and its applicability to sugar-cane are, however, sufficiently perceptible at present. As a proof of this, we may state that the international jury at Paris has awarded a gold medal to Mr. Minchin for his remarkable and important exhibits. There is one important point yet to be mentioned with regard to the diffusion process, viz: the utilization of the cane-trash as a fuel. This seemed to be a difficulty at the outset, since it was thought that the cutting of the cane into such small slices as are required for diffusion would prevent the trash from being used as a fuel. This has, however, been disproved by experience. The trash can be dried by simple exposure to the sun, and it is found to dry much more easily than fresh cane. After this it burns perfectly well upon a suitable grate, so as to be fully equal in this respect to the trash from the cane-mill. The Aska factory is now about to be considerably enlarged, and fitted out with complete apparatus for sugar manufacture by the diffusion process on a very large scale. We also understand that the diffusion process is shortly to be introduced in Cuba and in some other sugar-cane growing countries."

VII.—ENAMELLING AND BRONZING.

PLEISCHL'S ENAMELS.

Many inventors have occupied themselves with the endeavor to discover a vitreous enamel for metals which should combine the properties of durability, freedom from noxious ingredients, and unalterability by contact with the substances contained in the vessels to which it is applied. Enamels possessing these qualities to a great degree are already in use in this country, but there are none which will bear flexure or rough treatment to any extent without cracking or scaling off, though they may bear for a time sufficiently well the ordinary variations of heat to which, for culinary purposes, they are subjected. Something apparently very superior to this was exhibited in the Austrian section of the Exposition by Mr. Adolph Pleischl, of Vienna. Plates of copper were shown by him covered with a glassy coating, which bore exposure to heat and resisted the action of acids, and possessed at the same time the additional property quite as important as either of these, of allowing the the plate to be bent to an acute angle without either scaling or cracking. Many articles designed for domestic use or for chemical purposes were embraced in the collection of Mr. Pleischl, and according to the statement of the exhibitor, it had been thoroughly tested for both these purposes with results entirely satisfactory. According to the same authority this enamel is free from lead or zinc. It is not liable therefore to the serious objection to lead glazes, of contaminating liquids contained in the vessels coated with it with poisonous salts. It endures very rough treatment; bears hard scratching with a knife without losing its polish or showing any trace of the implement; may be heated to any degree, even to redness, and it continues to be perfectly sound, however the vessel may be indented or distorted.

No information could be obtained as to its composition. A letter addressed to Mr. Pleischl himself, at Vienna, elicited only some interesting statements as to its durability, but none as to the materials used in preparing it. It has been in use in the imperial-royal general hospital and in the foundling hospital at Vienna for many years. The large kettles in the laundry of the first of these establishments, after having been in daily use for years, and during sixteen hours each day, show no signs of change. In the second, the great iron pots of the cook-house after nine years of constant service, are equally unchanged. It has been used for purposes of galvanic gilding without being affected by the chemicals employed. It bears a dry heat to redness, as above stated, the only precaution necessary to be taken being not to cool it suddenly by contact with water. It is harder than glass, which it scratches, and is not even scratched by scouring with sand, so that the vessels coated with it may be cleansed in the most thorough manner that may be desired. And finally, if after many years of hard service the vessels covered with it begin to fail, it admits of repair. The bottoms can be

replaced and enamelled anew, restoring at once the sightliness and the usefulness at the same time. Mr. Pleischl also shows specimens of calking pitch for ships, which have a very powerful adhesion to wood, are not affected by sea-water, and have the great advantage of not being affected by the heat of the sun. It is stated that the Austrian navy has introduced this material in preference to all others hitherto employed, and that it has proved very satisfactory. An article similar in appearance to this calking pitch, but different in its composition, is Mr. Pleischl's varnish for iron vessels and pipes, which is now largely used in Germany for water-tanks, buckets, and other vessels intended for storing fresh water. This varnish is applied in a liquid state, and dries after a few hours, and is perfectly insoluble in water and impervious to liquids. It stands a very considerable pressure without cracking. Some trials made at Vienna show that a leaky cast-iron pipe, when covered with a coating of this paint, withstood a pressure of one hundred and fifty pounds to the square inch without showing the smallest signs of porosity. There can be no doubt that a material of such useful qualities, and which, to judge from the price-list issued by the maker, can be produced at very moderate rates, is likely to find a very wide range of application.

WERNER'S PATENT GLAZE FOR CASKS.

Another very excellent coating for the interior of casks was exhibited by Messrs. J. Werner & Co., of Mannheim, Baden. The magnitude and importance of the beer-brewing industry of the United States render every such really efficacious invention a matter of interest. In regard to this material, as to the former, the composition is unknown, but the following statement as to its merits is given in the language of the inventors, in reply to an application for information:

"Our patent glaze is not only a substitute for the pitch used in breweries hitherto for the purpose of isolating the inside of casks or kegs; it also gives to the brewer the most reliable security, when applied on fermenting tubs or coolers, that the process of fermenting, which is at all times a vital question and of the greatest importance for the brewer, accomplishes itself in a faultless manner, which is far superior to any other mode existing.

"The glaze was invented in 1860 by and patented to Mr. Werner, and has since that time introduced itself in several thousands of breweries all over this continent.

"The patent glaze is superior to any pitch or rosin ever known, because it never cracks or comes off; it is put on cold and with a bristle-brush; when extensively used, it is cheaper than pitch; it is a real preservative for casks and kegs; it communicates not even the slighest taste or smell to the beer. Whereas, on the other hand, pitch or rosin always cracks or comes off in pieces; must be burnt in, and has often been the cause of loss of life and property; it is very expensive, because the manipulation of burning it in absorbs and destroys the strength of the wood, so

that in a couple or three years new casks or kegs are unfit for further use; it ever gives to the beer a sappy, more or less disagreeable taste and flavor.

"All periodical papers and books treating on beer-brewing have paid great attention and warmly recommended the patent glaze, not, however, in the manner and way of 'puffing,' but on the strength of a previous strict trial and impartial examination. Such papers are:

"*Der Bierbrauer*, edited and published by Doctor Habich, at Wiesbaden; *Der Bayerische Bierbrauer*, edited by Doctor Lintner, professor of chemistry and director of the Royal Brewing Academy at Freising, near Munich, Bavaria, and published by E. H. Gummi, at Munich; the *Deutsche Industrie Zeitung*, edited and published by Mr. Robert Binder, at Chemnitz, in Saxony."

The inventors are desirous to introduce this article into the United States, and express the belief that "any person who takes hold of this matter and is sustained by us in regard to the purchase of raw material, as well as through the high recommendation of European firms in brewing, of the first reputation, will realize a fortune in the United States in less than three years."

TUCKER'S BRONZED IRON.

One of the products in the American department, which was looked on with particular favor, was exhibited by Mr. Hiram Tucker, of New York, under the name of bronzed iron. The objects in the collection of Mr. Tucker were certainly very beautiful, resembling very closely real bronze; and the relative cost is so much in favor of these imitations as to insure them an extensive popularity. They are said to have been already well received in France. The following notice of this useful invention is from Engineering:

"The name bronzed iron is given to Mr. Tucker's productions on account of their having the color and appearance of bronze castings, although the articles are not coated with bronze, nor with copper, or any other metallic compositions such as are usually employed in the manufacture of imitation bronze. Mr. Tucker's invention consists in treating the iron castings with vegetable oil at an elevated temperature, so as to produce upon the metallic surface a skin of oxide, which, in combination with the decomposed organic substance, gives the desired color and appearance. The castings, when finished and cleaned, are carefully covered with a liquid oil all over their surface, and particular attention is paid to the removal of all surplus oil, so as to leave only an extremely thin coating upon the metallic surface. In that state the iron casting is ready for the oxidizing process. It is brought into a stove heated to the temperature which decomposes the oil without charring it. This temperature is the same which will impart to cast iron a blue tint when exposed to it, with a clean metallic surface. At this temperature, therefore, the double process of oxidization of the iron and of decomposition

of the oil takes place simultaneously, and the castings are covered with a brown coating of oxide, which remains fixed to the surface with great durability, protecting the iron from further oxidation, and having the same lustre and metallic appearance as real bronze. The durability of this 'bronzing' is very considerable, and even those spots which, by constant wear, lose their superficial coating of oxide after some time, maintain the original brown color, since a new coat of brown oxide of iron is formed under the influence of the atmosphere, which makes the difference between the injured parts and those which have maintained their original color scarcely perceptible. Mr. Tucker's bronzes are, of course, much cheaper than real bronze articles, and they also compete to advantage with imitation bronze, over which latter material they also present the advantage of greater durability and beauty of form, since good cast iron fills the moulds with extreme accuracy, and allows of the reproduction of the finest mouldings given to the matrix. Mr. Tucker has started a manufacturing company for his bronzes at Boston, and is now about to introduce this manufacture into France."

PARKESINE.

A very remarkable product, called by its inventor, Mr. Alexander Parkes, of Birmingham, England, after his own name, was exhibited in the British department, in the form of buttons, knife-handles, combs, and various other articles of common use, of which it is the material. In some respects this substance resembles ebonite, or hard rubber; in others, bone or ivory; and in others, horn. It admits of being made colorless and translucent, or opaque and colored, at pleasure. The inventor has not fully disclosed the process of manufacture, or stated all the materials which enter into the composition, but asserts that it is cheaply made, the bulk being composed of substances having little value for other purposes. Cellulose or lignine, wholly or partially converted into the soluble form, is admitted to constitute the basis; but refuse cotton, or rags, or paper, may serve for the purpose, as well as articles of greater commercial value. This is combined with drying-oil and with other substances not named. Before the combination the oil is solidified by means of chloride of sulphur, united in varying proportions with naphtha or sulphide of carbon, the degree of hardness or flexibility of the product depending on the proportion used. By varying the materials every variety and degree of brilliancy of color may be obtained, and also every degree of hardness or flexibility, transparency, or opacity. When perfectly opaque and white, it is very beautiful.

This substance yields easily to the tool of the workman, and can be made to assume any desired form in the lathe, or under the hand of the carver. It may be made to imitate perfectly, wood, shell, horn, or ivory. It is unalterable under exposure to the weather; can be compressed in moulds into the form of ornaments or objects of use, such as the handles of knives, gravers, and tools in general; and can be com-

bined with other materials so as to impart to them its useful properties. Being a non-conductor of electricity, it is available for the insulators of telegraph lines, or the insulating portions of electrical apparatus of all kinds. One of its most important advantages is the property it possesses of forming a solution which serves perfectly to unite different portions into one mass, or to repair objects composed of it which may have been fractured by accident. In its flexible form it has been recently employed as a substitute for India-rubber in gas-pipes.

If the statements made in regard to this substance are correct, it cannot fail to come extensively into use. An examination of the articles which were on exhibition, manufactured from it, was sufficient to show, that in regard to strength, beauty, and apparent serviceability, it is not inferior to any of the substances which it is made to resemble; but as to its original cheapness, or the durability of its good qualities, it was of course impossible for the cursory observer to judge. From the fact that the invention dates back to a year earlier than that of the Exposition of 1862, in London, it would seem as if, in regard to these particulars, some room remains for doubt.

CHAPTER X.

DIVING AND RESPIRATORY APPARATUS.

SUBMARINE ARMOR—ANTIQUITY OF ITS USE—THE DIVING-BELL—DIVING APPARATUS OF THE NEW YORK SUBMARINE COMPANY—DIVING APPARATUS OF ROUQUAYROL AND DENAYROUZE—DIFFERENCE OF PRESSURE WITHIN AND OUTSIDE OF THE REGULATOR—FORM OF AIR PUMP EMPLOYED—USE OF APPARATUS FOR CLEANING BOTTOMS OF VESSELS—LIFE-SAVING RESPIRATORY APPARATUS.

I.—DIVING APPARATUS.

Submarine armor, with provision for the respiration of divers at considerable depths beneath the surface of the water, and designed to be used with or without diving-bells, is not a new invention. To say nothing of the earlier forms of apparatus of this kind of which descriptions remain, but which were apparently little more than projects, the diving dress of Klingert, of Breslau, appears to have been very successfully used as early as 1798. This consists, first, of a metallic cylinder with a hemispherical top, intended to cover the head and to come down below the shoulders of the diver; and, secondly, of a cylindrical metallic protection for the chest, meeting the head cover in a close joint, which was secured by an exterior jacket of leather bound firmly at top and bottom to the two cylinders by means of metallic hoops or bands secured with screws. The arm holes were cut in part out of the upper and in part out of the lower cylinder, the sleeves of the jacket covering them, and the sleeves themselves were made sufficiently tight just above the elbow to prevent the entrance of water, the fore-arm remaining uncovered. Leather drawers, extending to the knee and strengthened against the pressure of the water by an interior frame of iron, completed the dress. These, like the sleeves, were secured against the admission of water by tight ligatures, and at the top were connected with the metallic chest protector by means of a firmly screwed metal hoop. Glazed apertures in front of the eyes permitted the diver to look about him. Respiration was provided for by means of flexible tubes extending above the surface of the water, one for the purpose of admitting the air to the lungs, and the other for the purpose of discharging it. The first terminated within the helmet, in a mouth-piece of ivory, and, the mouth being kept always closed, exhalation took place through the nostrils, the discharge air escaping through the second tube. To counteract the buoyancy of the apparatus the diver suspended weights to his waist. These being properly adjusted, he was able to walk about upon the bottom, and to use his arms for the performance of any required work.

The disadvantages of an apparatus of this kind in the case of any considerable depths are obvious. Though the head, chest, and limbs are protected, the extremities are exposed to the full pressure of the water; and this, not being counterbalanced by any corresponding pressure on the protected parts, must soon become intolerably painful. Yet, for moderate depths, it was practically found to be quite serviceable.

Mr. Klingert endeavored, and in a measure successfully, to obviate the disadvantage just spoken of, by providing an air reservoir, to be sunk at the same time with the diver, and designed to furnish him with air under a compression corresponding with his depth. He gave to this reservoir a cylindrical form and a capacity of fifty-eight cubic feet, which he considered to be a sufficient supply to last one man two hours. The cylinder was so ballasted as to float upright when filled with air of ordinary density, exposing only about one foot of its height above the water. But it was provided with a movable bottom in the form of a piston, which could be controlled by a rack and pinion worked by a crank. By operating the crank so as to drive in the piston, the buoyancy of the cylinder would be correspondingly diminished, and the whole apparatus would sink. The breathing tube of the diver was to be connected with this reservoir, and as it rested on the bottom, he could increase or diminish the density of the contained air at pleasure, by turning the crank. The air, after inhalation, could be exhaled into the reservoir again, or be permitted to escape through a properly arranged valve in the armor. The first mode would provide against variation of pressure, although attended with a gradual vitiation of the purity of the air. But as it is experimentally proved that the same air may be safely breathed twice over, and as ordinarily a man does not inhale more frequently than fifteen or twenty times a minute, nor receive into his lungs more than twenty-five or thirty cubic inches of air at each inhalation, it is proved by an easy calculation that the fifty-eight cubic feet of Mr. Klingert's reservoir would suffice for the support of a diver much longer than he claimed, even if no portion of it were allowed to escape after being breathed.

Tonkin's submarine armor, employed early in this century on the British coast, and especially in the recovery of valuable articles from the India ship Abergavennie, which foundered in 1804 near Weymouth, was in principle similar to Klingert's, but was stronger and more elaborate. It resembled very much the military armor of the early and middle ages, being formed of metal plates articulated with each other, but covered also with an exterior dress of water-tight leather, to secure against leakage. The protection extended to every part of the person except the arms, the feet and legs being covered with iron boots, though the larger plates covering the body were made of brass. For the supply of air to the diver an elastic tube was employed, as in the case of Klingert's apparatus, communicating with an air vessel in a boat at the surface. Into this vessel air was thrown by a forcing pump until its elasticity was sufficient to counteract the pressure of the water. The diver employed no

mouth-piece, but breathed the air within the case, permitting it to escape, as it became vitiated, through a valve provided for the purpose. To compensate for this loss the pump was kept in action, so as to maintain the pressure as nearly as possible uniform. A plate-glass window, eight inches in diameter and one inch thick, enabled the diver to see the objects about him, and to perform the work required.

The diving-bell, a machine often used in subaqueous operations, and which requires no special provision for the protection of the diver's person, seems to have been very early known, and is said, in fact, to have been employed among the Greeks of the time of Aristotle. Its earliest appearance in western Europe took place near the beginning of the sixteenth century. But it was more than two hundred years later that this contrivance was made practically available for use at any but very moderate depths. The pressure of the water necessarily reduces the bulk of the air contained in the bell in proportion to the depth of the immersion, so that at the depth of five or six fathoms the bell is half full of water. In 1715, the celebrated Dr. Halley suggested a simple mode of displacing the water by the addition of a fresh supply of air. His method consisted of sinking barrels containing air to a level a little lower than that of the bell, and afterwards discharging their contents into the bell by means of pipes proceeding from the top of the barrels, while water was admitted at the bottom. This expedient also sufficed to maintain the purity of the air in the bell; for, inasmuch as the portion vitiated by respiration would accumulate at the top, on account of its higher temperature, it could be from time to time discharged by merely opening a cock, while a fresh supply was received below.

Dr. Halley also contrived a very ingenious apparatus to enable the diver to leave the bell and still to have the benefit of the air which it contained, without encumbering himself with any kind of armor except what may be called a species of helmet. This helmet was, in effect, nothing more than a smaller portable bell, covering the diver's head, and descending far enough for his security without embarrassing the motion of his arms; but entirely open below, and in the dimensions of its upper portion little larger than a cap. The front of this cap was strongly glazed, and, in order to prevent obscuration of the glass by the condensation of vapor from the breath, the cap in front of the face was considerably enlarged or prolonged. A tube from the cap leading to the interior of the bell supplied the wearer with the necessary air. This tube was furnished with a stop-cock, at the command of the diver, for the purpose of regulating the flow of air; an important consideration, since this flow would be from the bell to the cap or from the cap to the bell, according as the level of the water in the one or the other should be highest. When the diver, in leaving the bell, was obliged to descend beneath its rim, the water would, of course, fill the cap entirely, expelling all the air, unless the cock were closed. The same accident, in the absence of a similar precaution, would occur every time he descended to a lower level,

in consequence of the inequalities of the bottom, or every time he had occasion to stoop. On the other hand, if he mounted to a level higher than that of the water in the bell, the flow of air into the cap might be greater than necessary for his comfortable respiration, or might be even wasteful, unless it were regulated by a partial cut-off.

Important improvements upon the diving-bell of Dr. Halley were made at a period somewhat later, by Mr. Spalding, of Edinburgh. One of these was a simple provision against the possible accident of the overturning of the bell by the irregularities of submarine rocks, or the spars of a sunken vessel, catching the edge of the bell on one side while the persons above continue to let it descend. This dangerous possibility, which experiment had proved to be very real, was provided against by suspending the weight employed as a sinker at some little distance below the bell, while the bell itself was only ballasted so as to stand upright, but made too buoyant to sink. By means of this arrangement the weight would first strike the rocks, and the progress of the descent would be arrested, until the divers could reconnoitre the nature of the surface beneath them. The bell could then be depressed to the point desired, by hauling on the weight. A simpler mode, however, was devised by Mr. Spalding for regulating the descent and elevation. The bell was made of considerably larger vertical dimensions than had been previously used, and a horizontal partition divided it into two chambers. The lower of these was occupied by the divers, while the upper was used as a regulator of buoyancy, somewhat on the principle of the air-bladder in fishes. When this was entirely filled with water, as it might be by opening a cock in the top for the discharge of any air it might contain, and another one at a lower point for the admission of water, the bell would descend. On the other hand, when entirely filled with air by the admission of air from the lower chamber while the water was permitted to escape from the bottom, the loss from the lower chamber being in the mean time supplied from the air-barrels above described, the apparatus became sufficiently buoyant to rise independently of any assistance from the persons at the surface. This last was a very important improvement, since it placed the divers beyond the reach of danger from the breaking or entangling of the suspending ropes.

Hitherto the material employed in the construction of the diving-bell had been wood, and the form given to it had been that which is implied in its name. In 1788, or somewhat later, Smeaton, the eminent engineer, whose name is associated with so many of the important public works constructed in Great Britain toward the close of the last century, conceived the idea of substituting cast iron instead of wood, and of giving to the machine the form of a rectangular box. He also greatly increased its dimensions, making it four feet and a half in length and height, and three feet in width, with a capacity therefore of sixty cubic feet. He also discarded the method of supplying air by sinking barrels, and subsituted a forcing pump, by means of which he maintained a constant stream,

which was conducted to the bell through a flexible tube. By adopting a material for the bell of so great specific gravity as iron, it became practicable to dispense with the weights which had been previously attached to the sides of the machine. The total displacement exceeded two tons. A weight was given to the bell approaching two tons and a half, a large portion of this weight being accumulated around the rim in order to secure stability in the upright position.

The diving-bell in its perfected form will thus be seen to be a cumbrous machine, requiring a considerable force for its management. Its capabilities of usefulness are such that it will probably not be wholly superseded by any other contrivance for facilitating subaqueous explorations, or the application of human labor to operations beneath the surface of the water; but the difficulty and expense attendant on its use are such as practically to limit its employment to constructions of great magnitude and to works of long continuance. For the ordinary purposes of diving, some description of armor for the protection of the person, which can be used under any circumstances, and without elaborate preparation, will be generally preferred; and, indeed, without such armor, the usefulness of the bell itself must be greatly restricted. The latest attempts to improve upon the apparatus for diving have related to diving dresses or diving armor, and to the means of providing for the comfortable respiration of the divers.

DIVING APPARATUS OF THE NEW YORK SUBMARINE COMPANY.

There were exhibited at the Exposition of 1867 two descriptions of diving apparatus, either of them very superior to the forms heretofore in use, and each having merits peculiar to itself. One of these was exhibited by the New York Submarine Company, a corporate association organized for the purpose of undertaking submarine work of any description, such as the construction of submarine foundations, the raising of sunken vessels, the buoying of vessels over bars or sand-banks, and the examination and repair of ships' bottoms, or of any existing permanent works covered by the water. The part of their apparatus which is designed for buoying and lifting operations is very simple, but is no less interesting. Heretofore, in such operations, boats, barges, or casks, in great number, have been lashed to the vessel to be lifted, after having been filled with water and submerged, and these have been rendered buoyant by removing the water, which, in the case of boats, is effected by pumping, and in the case of barrels by the use of the compression air-pump. The buoys of the New York company are huge canvas sacks coated with India-rubber, and externally strengthened and guarded by a network of strong cordage. Each has a capacity of five hundred and fifty cubic feet, and a lifting power, when inflated, of about fifteen tons. These buoys are connected together in pairs, one on each side of the vessel to be lifted, by means of chains which extend beneath the keel. In order to facilitate the repairs of the buoys, each is fitted at the upper

end with a ring, to which a copper plate is secured, so that it can be readily removed for giving access to the interior. To this manhole plate is fitted a safety-valve for relieving the buoy of the overpressure as it rises to the surface; and the lower end of each buoy is also fitted with a metallic ventilator and safety-valve, both for convenience in handling and to prevent the bursting of the buoy in case of its rising too rapidly to be relieved of the internal pressure by the upper valve alone.

The buoys are of course attached in a collapsed condition to the vessel to be lifted. Air is then admitted to them from the reservoirs in the attending vessel, in which there has been accumulated a great volume, reduced to the bulk of about five hundred feet, under a pressure of thirty-three atmospheres. The reservoirs, which are six in number, are kept charged by means of powerful compression pumps, one of which, capable of delivering one hundred and twenty cubic feet per minute, is employed to commence the compression, and the other, of smaller capacity, to carry up the pressure to the maximum.

The buoys, before inflation, are fixed to the sides of the vessels by divers, who are fitted out with the submarine armor and breathing apparatus which is peculiar to this company. This armor consists, for moderate depths, of a strong helmet of metal, cushioned in the interior, and having a plate-glass window in front, and a water-proof dress entirely enveloping the person, which is secured to the helmet very much in the way employed by Klingert. This dress is sufficiently weighted to sink the diver in the water, and to enable him to stand firmly when it is necessary to rest upon the bottom. In order to provide for respiration, an air reservoir is fastened upon his back in the manner of a knapsack, into which a sufficient amount of air has been compressed to serve him for several hours. This air is conducted into the interior of the dress by means of a pipe provided with a cut-off valve under the diver's control. A cock on the top of the helmet permits the discharge from time to time of the air which has become foul by breathing.

For depths sufficiently great to make the compression of the folds of the dress against the person an inconvenience, there is provided what is called an inside protector, formed of a series of ribs or rings surrounding the person and the lower extremities, which prevents collapse.

The diver also wears, secured beneath his arms, a pair of buoys, designed to raise him in the water at his pleasure. These are water-tight sacks, resembling the India-rubber life-preserver, and are inflated, when necessary, from the reservoir at his back.

A printed description of the apparatus furnishes the following additional particulars:

"In this dress and outfit the diver is independent of any connection with the surface, and, by means of appliances fitted in his helmet, he is able to take his own bearings and directions, and keep his own time. By the inflation of the peculiar life-preserver with which he is provided, the diver can ascend to the surface at pleasure, and when there, will be head

and shoulders out of water, and can open his helmet himself. This diving armor removes the danger of suffocation incidental to the usual method of pumping the air to the diver, arising from the kinking or injury of the hose which conveys the air down to him, and from the imperfect action of the pump. By means of his buoys he can rise or sink to any depth and there suspend himself. This improvement is of great value for the examination of vessels' bottoms. The security of the diver for his air, both for breathing and for remounting to the surface, may be exemplified by the fact that a diver, wearing this dress, has, at the depth of forty feet, sent up a column of air which raised a fountain or jet three feet in height at the surface. Ordinarily, a knapsack or reservoir sufficient to maintain a four hours' supply of air for the diver will be large enough.

"For facilitating operations under water, the Submarine Company employ a submarine lamp, which is also fed by compressed air, and requires no communication with the surface, and which may be carried by the diver or suspended at any required depth, and will, by means of its reflector, cast its light many feet horizontally through the deepest water. This is a great auxiliary to the submarine workman, enabling him to inspect wrecks, examine and repair the copper and bottoms of vessels, and generally to see what he is doing.

"The apparatus which we have described has already been used by the company, in many instances with great success. On the occasion of the first wrecking cruise of the company's vessel, the Saxon, from New York, the buoys were attached to a sunken vessel of two hundred tons in between four and five hours, and on their being inflated the vessel was raised to the surface in five minutes. The steamship Coffee, a blockade-runner, which was submerged in twenty-four feet water, was the next vessel raised by the aid of the apparatus, and among those which have since been lifted by the company are the schooner Tortugas, sunk in the harbor of Key West, Florida, and the W. E. Bartlett and the William Carleton, schooners sunk in Chesapeake bay; and a large quantity of valuable cargo was also raised from the brig William Edwards, a vessel which was sunk by a collision with the steamer Ariadne about eight and a half miles out to sea and thirty-five miles south of Sandy Hook, in seventy-five feet water. The company is now also perfecting a system for lifting and conveying vessels over shoals and bars, the draught of the vessels being reduced to the required extent by the application of buoys of a similar kind to those employed for raising sunken ships."

DIVING APPARATUS OF ROUQUAYROL AND DENAYROUZE.

Another form of submarine armor, differing chiefly from the foregoing in the provision made for the respiration of the divers, was exhibited by Messrs. Rouquayrol and Denayrouze, of Paris. A practical illustration was daily given, during the continuance of the Exposition, of the use of this apparatus, in a huge tank erected near the bank of the Seine, where

one or two divers were constantly exhibiting to curious crowds the complete command which it enabled them to exercise over their movements in the water. This curious spectacle was commonly spoken of as "the human aquarium."

The distinctive feature of the invention of these exhibitors consists in a contrivance called by them the "regulator." The design is to maintain, what is not done in any other form of diving armor, a constant equality of pressure between the interior and exterior of the chest. The diver carries with him, as in the case of the New York Submarine Company, his provision of compressed air for breathing in a reservoir secured to his back, but this air, instead of being admitted directly into the dress by means of a stop-cock operated by the diver himself, passes first through a chamber in which the pressure is automatically maintained exactly equal to that of the surrounding water. The construction of this regulator is very simple, and its operation is easily intelligible. Externally it appears to be a cylindrical box, about eight inches across, and two or three inches deep, placed upon the top of the air reservoir, with which it is firmly connected. The lid of this box is a circular metallic plate not quite so large in diameter as the box itself, but united to the circumference of the box by means of a flexible diaphragm. Thus, this disk has a certain freedom to rise and sink, while maintaining generally its position concentric with the cylinder, and closing the cavity against the admission of water or the escape of air. At the centre of this box in the bottom is a small valve opening upward, through which communication takes place when necessary with the chamber of compressed air. The valve is a spindle valve, with guides above and below, and is ordinarily kept closed by the upward pressure of the confined air beneath. From the centre of the movable lid above described descends a stem, which has guides like the spindle of the valve beneath, and which, as the lid descends, may strike upon the spindle and open the valve. The effect of the opening will be to allow the escape of a small portion of the confined air; and this, by raising the lid, will relieve the spindle, and permit the valve once more to close. The latitude of motion allowed to the lid is determined by two stops affixed to the central stem, and these stops admit of adjustment at the pleasure of the constructor, or of the person who is to use the apparatus.

It is with the cavity of this regulator that the lungs of the diver are in communication. A tube leading from the regulator through the dress terminates in a mouth-piece which resembles the mouth-piece of a speaking trumpet closing over the lips, but is provided with two knobs or projections intended to be held between the teeth. The nostrils are also closed by a compressing nose-piece provided with pads, so that the diver is compelled to exhale as well as to inhale through the mouth. As his lungs expand, the quantity of air in the regulator diminishes and the lid descends. The adjustments are such that when the inhalation is partially advanced—say to the extent of one-half—the

valve of the reservoir is opened by the descent of the movable disk, and a quantity of air escapes sufficient for the completion of the inhalation. In exhaling, the air is driven back through the same tube into the regulator again, until the movement of the disk is arrested by the stop fixed on the stem for that purpose, and the remainder of the breath exhaled escapes through a valve attached to the tube. This valve is of a very simple kind. It consists of two thin sheets or ribbons of rubber cemented together at their longitudinal edges, but open at their extremities. One extremity is fixed to the orifice of escape; the other is free in the water. The two sheets are kept firmly closed by the external pressure until the regulator ceases to admit more air, and they then open freely to permit the excess to escape.

The partial return of the air to the regulator is a measure of economy, and is attended with no disadvantage, since air can always be safely breathed a second time. It is known, in fact, that air which has once been inhaled contains somewhat less than five per cent of carbonic acid, and, after a second inhalation, about ten per cent. If we suppose the regulator to contain originally one hundred and fifty cubic inches of air at the ordinary atmospheric pressure, and that a man requires on an average thirty cubic inches at each inhalation, then, provided the stops are so adjusted that the diver returns one-half of this, or fifteen cubic inches, to the regulator at each exhalation, there will be, in the first instance, three-quarters of a cubic inch of carbonic acid returned, to be mingled with one hundred and forty-nine of pure air. At each successive exhalation the proportion will be increased, but, under the circumstances supposed, the maximum of impurity reached can never exceed five per cent. Supposing the air in the regulator to be of greater density, the ratio of maximum impurity will be proportionally less; since the mass of air received into the lungs will be greater under a given bulk, while the amount of carbonic acid generated will not be correspondingly increased. It would be quite safe, therefore, to adjust the stops for great depths in such a manner as to permit a larger portion of the air than one-half to be returned to the regulator. It has indeed been experimentally ascertained that a man in a diving-bell, in five or six fathoms of water, will be able, after a full inhalation, to hold his breath twice as long without inconvenience as he can in the atmosphere above the surface. This is intelligible when we consider that, at the depth supposed, the lungs contain, under the same bulk, twice the usual quantity of air.

When it is stated that the regulator furnishes air to the lungs at a pressure equal to that of the water in which it is immersed, it will be understood of course that there is a difference too small to be of any practical importance, occasioned by the resistance to opening of the little valve communicating with the reservoir. The amount of this difference may be calculated, when the diameter of the valve and the interior diameter of the reservoir are given. As there are two sizes of the

apparatus employed, in one of which, designed for moderate depths, the pressure of the confined air is maintained, by means of a compression pump in a boat at the surface, at about one atmosphere only above that of the water at the diver's depth, the dimensions given to this are less, and the valve is made larger, than in the case of the other, which is called the high-pressure apparatus. A general expression may be found, however, for the difference of pressure within and without the regulator, which will apply to either case. Let D represent the interior diameter of the regulator, and d that of the valve. Put P for the downward pressure per square inch acting upon the regulator at the moment when the valve yields to the force exerted on the spindle, and p for the pressure per square inch exerted by the confined air in the reservoir. Put, finally, p' for the pressure per square inch of the air in the regulator. We wish to obtain an expression for the difference $P—p'$.

The total downward pressure upon the surface of the movable disk is equal to $\frac{1}{4}\pi PD^2$.

The total upward pressure on the same surface is $\frac{1}{4}\pi p'D^2$.

The upward pressure on the valve is $\frac{1}{4}\pi pd^2$.

And the downward pressure on the same is $\frac{1}{4}\pi p'd^2$.

On supposition of equilibrium, the sum of the pressures in opposite directions must be equal.

Whence,

$$\tfrac{1}{4}\pi PD^2+\tfrac{1}{4}\pi p'd^2=\tfrac{1}{4}\pi p'D^2+\tfrac{1}{4}\pi pd^2.$$

$$\text{or, } (P—p')D^2=(p—p')d^2.$$

$$\text{And } P—p'=\left(p-p'\right)\frac{d^2}{D^2}$$

This being the condition of equilibrium, the slightest diminution of p,' produced by the act of inhalation, will cause the valve to open.

When the low-pressure apparatus is used, $p—p'$ may be taken at about one atmosphere. Assuming the depth to be six fathoms, the pressure (in sea water) will be sixteen pounds to the square inch, to which must be added fifteen pounds for the natural atmosphere, and, to be strictly accurate, the weight of the movable disk; but this may be thrown out of the account as unimportant. In this apparatus $D=200$ millimetres, and $d=7$ millimetres.

Whence,

$$P—p'=15\frac{7^2}{200^2}=15\frac{49}{40000}=0.018375,$$

or less than the fiftieth part of a pound per square inch. The difference of pressure within and without the regulator, that is to say, in the lungs and on the chest, would correspond to a difference in the barometric column not so great as four one-hundredths of an inch.

In the high-pressure apparatus, the value of D is 300, and that of d, $3\frac{1}{2}$. At the same time, the pressure in the reservoir, p, is carried up as high as forty atmospheres, while p' is dependent on the depth of immersion.

The reservoir in this case is not connected with the pump above, but the diver continues below until he finds his supply to be nearly exhausted, and then returns to the surface to replenish his stock. Whatever the depth to which he intends to go, he must begin drawing his breath from the reservoir from the moment of first immersion; and hence, $P-p'$ will have a value which is maximum at the surface, and which diminishes as he descends. The most unfavorable supposition will therefore be to make $p-p'=39$ atmospheres$=585$ pounds per square inch.

Whence,

$$P-p'=585\frac{3.5^2}{300^2}=0.0796,$$

or about two twenty-fifths of a pound per square inch, which is about four times as great as in the former case, but still insignificant.

Under the largest variation of conditions, therefore, this apparatus furnishes the diver with air for respiration at a pressure corresponding exactly with the depth of his immersion, and thus effectually removes one of the greatest disadvantages attending his difficult labor.

The inventors of this apparatus have made no special provision of buoys to enable the diver to raise himself in the water, but the dress itself is made to serve the purpose of a buoy, air being admitted into it from the reservoir at pleasure. The diver can, therefore, at any moment, rise to the surface with the greatest facility.

The capacity of the largest high-pressure reservoir is thirty-five litres, or 2,135 cubic inches. Filled with air compressed to forty atmospheres, it contains a quantity equivalent to 85,400 cubic inches at the ordinary atmospheric pressure, and this will suffice for the respiration of a single person for from four to six hours.

The depth to which a diver can descend is limited by the exhausting effect of the increasing pressure of the water upon his limbs and indeed upon his whole person. For whether the dress is maintained out of contact with his body, by internal armor plates or frames, or not, there must always be a pressure of air within the dress equivalent to the water pressure without, or the consequences will be very serious. The Catalonian coral divers descend thirty-eight or forty metres, and are thus exposed to a pressure of four atmospheres in addition to the natural atmosphere, or five in all; but they scarcely remain more than twenty minutes at this extreme depth. Lieutenant Denayrouze is of opinion that a practiced diver diver, with his regulator, may descend at least fifty metres, going down and coming up slowly. The effects of pressure are much more endurable when the increase is gradual than when it is sudden; and it is observed that the removal of heavy pressure, as in case of a very rapid ascent, is attended with sensations more disagreeable than attend its increase. The experienced diver will therefore rise from great depths very deliberately, at the rate at first of only a metre or two a minute. By the proper management of the air admitted for buoyancy he can regulate his rate very accurately.

A peculiar form of air-pump is employed by these inventors for charging their reservoirs with compressed air. The barrels, instead of the pistons, are movable, the former being inverted relatively to the usual arrangement and attached by their closed extremities to the working lever. The packing is of dished leather, and water is thrown in, in small quantity, at every stroke of the pump; so that the piston is always covered with a liquid stratum, and all leakage of air is effectually prevented. By an ingenious combination of levers, four pumps are simultaneously worked, each having the same length of stroke, but not the same cross section. The air is received, at a pressure of one atmosphere, by the largest of these, and transferred to the second under a pressure of three and a half atmospheres. From this it passes to the third, with a pressure increased to six; from the third to the fourth with the higher pressure of sixteen; and from the fourth to the reservoir, at the desired final pressure of forty. The water introduced into the several cylinders has the effect to absorb a great part of the heat of compression, so that (it is stated) the fourth cylinder is always as cool as the first.

The principal use for which this apparatus was originally designed is stated by the inventors to have been to facilitate the cleansing of the bottoms of vessels, while at sea, of the barnacles and sea-weed which constantly accumulate upon them, and which greatly impair their sailing qualities. It is said to have resulted from an examination of the logs of the armor-plated steam vessels of the French navy, that these vessels lose about two knots in speed in the course of a year while at sea, in consequence of such accumulations. This deterioration involves an increased expenditure of fuel, and may, in actual service, be the occasion of disadvantages still more considerable. By actual experiment it has been found that with a moderate amount of labor periodically expended by one or two divers, the ship's bottom may be kept entirely free from these obstructions.

The arrangements by means of which the divers are enabled to gain access to the surface to be cleansed are very simple. A rope ladder with wooden rounds is carried under the hull, and secured on deck at both ends. The diver descends this ladder, carrying with him his implements, and also a kind of seat or step furnished with hooks to be attached to the ladder at the point where he commences operations. For the parts which, on account of the curvature of the vessel, or the neighborhood of the keel, he is unable to reach in this way, he takes advantage of his power to rise in the water by inflating his dress, and thus ascends into these spaces and lays himself alongside of the surface on which he is to operate.

Several commissions have been appointed by the French, British, Italian, and Dutch governments, to experiment and report on the merits of this apparatus, and the reports have been favorable in every case. The apparatus has therefore been recommended for adoption in the navies of all those nations.

II.—LIFE-SAVING RESPIRATORY APPARATUS.

An apparatus somewhat resembling the diver's dress, but designed to enable firemen or others to enter houses filled with smoke, carbonic acid, or other deleterious gases, was exhibited on the bank of the Seine, and also at the island of Billancourt, by Mr. A. Galibert, of Paris. It consists of a helmet and mask, protecting the face and eyes, and of a large reservoir of air, constructed of flexible materials, as, for example, leather or India-rubber cloth, containing a sufficient supply for the respiration of an individual for fifteen or twenty minutes at a time. This is strapped to the back of the person, while a tube proceeding from it conveys the air to the wearer's mouth. The mouth-piece resembles that of the diving apparatus of Messrs. Rouquayrol and Denayrouze, being held in like manner by the teeth of the wearer. The nostrils are also closed by means of a piece like that described as belonging to the diving dress just mentioned.

The weight of the reservoir is trivial, not exceeding a kilogram, and the price of the whole apparatus is but one hundred and twenty-five francs. It is not necessary to insist on the usefulness of a contrivance of this kind. It has been successfully employed on very many occasions of danger, and has been the means of saving many lives. Its usefulness is by no means confined to the case of burning buildings. The foul air of wells, vats, mines, sewers, &c., is the occasion of the loss of many lives annually, and frequently the number of victims is increased by the efforts which are made to save the first who are asphyxiated. In every such case, a person armed with the respiratory apparatus may venture, without the slightest inconvenience, into the midst of the noxious fumes, and may in general withdraw the sufferers in time for their resuscitation.

The dress may be put on in half a minute, and no longer time is necessary to inflate the reservoir. Should it be necessary to extend the time of use beyond that which the supply allows, the reservoir may be very quickly discharged and reinflated. The time when it is proper to renew the supply will be indicated by the increasing rapidity of the respiration, as the air is returned to the reservoir on each exhalation, and the rate of breathing is the measure of its growing impurity.

Numerous experiments on the use of this apparatus have been made in presence of commissions appointed by the board of health of Paris, by the minister of marine and the minister of public works of the French government, and by other authorities; and in consequence of the reports made upon the observed results, it has been introduced into the French navy, and into other branches of the public service of France. In the course of one of the series of experiments above mentioned, a member of the commission himself put on the dress and entered in person into a chamber which had been so thoroughly filled with smoke, carbonic acid, and other noxious gases, by burning in it damp straw, that it was almost impossible for any one to remain even in the adjoin-

ing apartment near the door communicating between the two, though the door was closed. He experienced not the slightest inconvenience from the experiment.

The simplicity and cheapness of this apparatus, and the complete immunity which it secures to the wearer from the effects of noxious gases under any circumstances, would seem to make it an almost indispensable addition to the resources of any properly organized fire department, and to recommend it especially to navigators, who by its means may often be able to check a conflagration occurring in the hold of a vessel, or between decks, which might otherwise soon become uncontrollable.

CHAPTER XI.

IMPROVEMENTS IN THE APPLICATION OF HEAT.

THE ECONOMICAL TRANSPORTATION OF HEAT—MARVAL'S HEATING APPARATUS—ITS APPLICATION IN BAKING AND IN OTHER INDUSTRIES—SIEMENS'S REGENERATING GAS FURNACE—ITS USE IN THE PRODUCTION OF GLASS—HOFFMAN'S ANNULAR BRICK FURNACE.

I.—TRANSPORTATION OF HEAT.

The economical transportation of heat from a furnace to the point of application is a problem of much interest. In the heating of dwellings the object is accomplished more advantageously perhaps by means of steam than in any other way. This method offers at once the combined advantages of economy, uniformity, healthfulness, and neatness. But steam as a carrier of heat is limited to a temperature much below what is required for many processes of industry, though this is not by any means true for all. In the chemical arts steam may often be thus advantageously employed, and this is likewise the case in many culinary operations, especially when such are conducted on a large scale. But there are some even among these for which it is not sufficient. The process of baking bread, for example, requires a temperature of five or six hundred degrees Fahrenheit; and this has heretofore been obtained only by the direct action of fire upon the walls of the oven, applied either internally before baking, or externally while the baking is going on. This very uncertain, irregular, and uneconomical mode of applying heat for such purposes has been effectually superseded by a recent invention of Mr. Joly de Marval, of Paris, in which a current of water confined in a tube is made the medium of transporting a heat of the most regular character from the source to the point of application, and of any temperature from two hundred to eight hundred or nine hundred degrees.

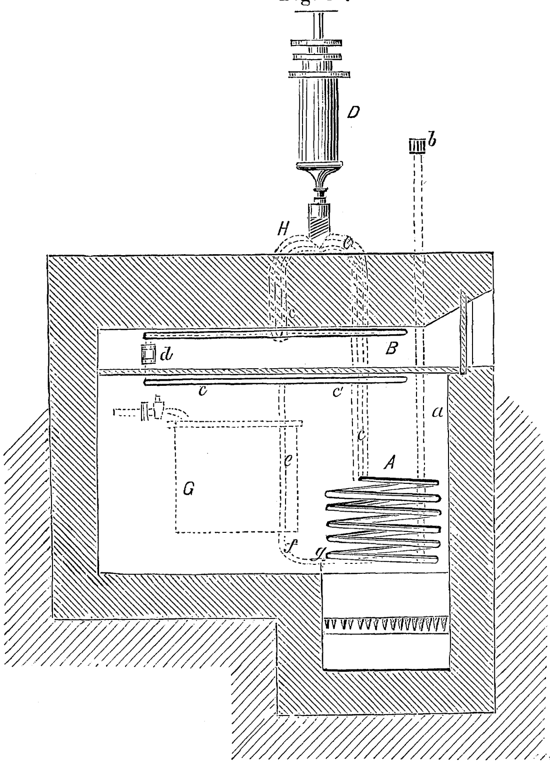
MARVAL'S HEATING APPARATUS.

The heat is imparted to the water by conducting the tube containing it, coiled into the form of a spiral, through the furnace itself, where the fire is in immediate contact with its surface. It is transported to the point of application by taking advantage of the mobility of fluids, and of their expansibility under the influence of heat. The furnace must be at a lower level than the space to be heated, and the tube at this latter point must be developed into other coils or zigzags, so as to present a large amount of radiating surface. Further, in order that the transpor-

tation of heat may go on continuously, the tube itself must be continuous or endless, so that as the water heated by the furnace rises on one side, that which has more or less wholly given up its heat may descend on the other. It is true that water raised in confinement to temperatures such as have just been mentioned, exerts a tremendous pressure upon the walls of the containing vessel; but it is also true that the danger of explosion from high pressure is less as the diameter of the vessel is less, and that small iron tubes of given thickness will bear a pressure which when stated seems almost incredible. Mr. de Marval has tested his tubes to seven hundred atmospheres, that is to say, to more than ten thousand pounds to the square inch. He subjects them ordinarily to a pressure not exceeding two hundred atmospheres, or three thousand pounds to the square inch.

The tubes are about three-quarters of an inch (eighteen millimetres, in diameter internally) and about twice as large (thirty-eight millimetres) externally.

Fig. 81.

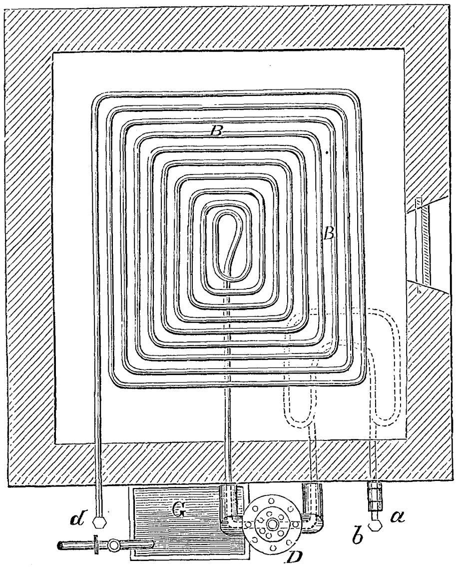


Marval's Heating Apparatus—section.

The manner of adapting this plan of heating to a large oven for the baking of bread may be understood by reference to the accompanying figures. Fig. 81 is a section in elevation of the oven and furnace; and Fig. 82 is a view in plan. The spiral in the furnace is shown at A directly over the bars of the grate. It ascends by the tube *c*, which is external to the furnace, and is protected by a sheath of sheet iron, makes a bend at H, where is attached the contrivance D, (to be presently explained,) and then forms a flat spiral B, as shown in Fig. 82, in the roof of the oven, where the coils are distant from each other little more than the diameter of the tube. From this spiral it is carried again outside of the masonry to the point *d*, seen in both figures; then it descends and re-enters to form a third spiral *ee*, under the floor of the oven, which last is formed of thin tiles which are soon heated through. Thence it descends after again passing out through

the wall by the straight tube e', which connects and is continuous with the original spiral A, at the bottom. This tube e' is not indicated in Fig. 82. M. de Marval causes this portion of the tube to pass through the water tank G, for the purpose of keeping up a constant supply of hot water for general uses.

Fig. 82.



Marval's Heating Apparatus—plan.

It will be understood that the expansion of water with increase of temperature is much greater than that of iron, and consequently that if the tube is absolutely full of water, the pressure which it is capable of exerting by its expansion as a liquid will be a great deal greater than that which would belong to steam formed at an equal temperature. It is necessary to provide against this; and such a provision would at first thought seem to be easily and effectually secured by leaving a small portion of the tube to contain air only. But inasmuch as the *circulation* of the liquid is the condition indispensable to the transportation of the heat, and as this circulation is determined only by the different densities of the water in the ascending and descending branches, it is evident that by admitting an air space or a steam space we should effectually arrest the operation of the contrivance. To provide against this, the attachment shown at D is added. This is a cylinder somewhat larger in diameter than the tube, and communicating with the latter at the bend H. Within the cylinder is a piston closely fitting by metallic packing and having a piston rod which is hollow and forms a communication between the cavity below the piston and the outward air. This piston rod is also very closely packed, so that the space within the cylinder is filled with air which cannot escape and which may be compressed to any degree. At the point *b*, in both figures, is seen the extremity of a tube which communicates with the lower spiral at the lowest point. It is through this tube *b* that the apparatus is charged with water. The piston in D being depressed to the bottom of the cylinder, and its rod being open to the air, the water rises regularly from the lowest point of the system to the highest, driving out the air before it, filling all the tube, and finally appearing in the interior of the hollow piston rod, which is the highest point of all. This rod is then firmly closed by screwing on an air-tight cap, and the tube *b* is secured in like manner.

The joinings of the tubes which form the several spirals are very

strongly secured. The extremities of the tubes to be joined are, in fact, cut with screw threads turning in opposite directions, one being a right-handed and the other a left-handed screw. A single nut, correspondingly cut in its two opposite halves, brings the tube ends together by one operation, a ring of copper being interposed to form a washer. After forcing the nut hard up, guard screws are driven firmly up against it on both sides, with an interposition of white lead or other drying cement.

Having thus described the general construction of this apparatus—of which an example on a large scale was in continual operation at the Exposition, and which was daily open for inspection at the bread-baking establishment of the inventor in Paris—its value, considered as an addition to the resources of this important industry, and not of this one alone, but of very many others to which it is equally applicable, may be best shown by presenting the substance of some extracts from a report made on the subject by Mr. Babinet, of the French Academy of Sciences.

"In studying this admirable apparatus," he remarks, "I recognize the fact that it takes up the heat of the fuel in the furnace with a simplicity and an efficaciousness *without parallel*, and conveys it at will to different places, making it subserve there various uses of the greatest importance. A long examination of the contrivance convinces me that the construction of its parts leaves nothing to be desired in regard to security, efficacy, and perfect performance, while it is nevertheless manifest that, in spite of the simplicity of the process, these results have only been obtained after long and expensive experiments which bring to mind those which preceded the creation of the locomotive. Everybody is acquainted with the *calorifères* and tubes full of water which carry slowly a moderate heat to a distance more or less removed from the furnace. Perkins obtained much more marked effects of the same kind, but without regularity of law; and I do not hesitate to affirm that the Messrs. Joly de Marval, in deriving heat from a furnace, ingenious in itself, and by means of tubes in which there is established an energetic circulation perfectly regulated, have made a fundamental discovery."

After remarking on some particulars of the construction, and observing that the durability of the tubes is such that they can be relied on for years without the necessity of repairs, he continues: "A furnace of several cubic metres capacity can be kept constantly heated to 300° C, (570° F,) and above, for twenty-four hours, at an expense for fuel of about five francs. I have inspected the interior of the oven, and a batch of large loaves was baked in my presence in half an hour. All who examined the loaves were satisfied that they were perfectly done through, having a golden and very inviting crust, and a crumb entirely uniform, being also without burns or knots. As I say all this from my own observation, I can affirm that into the high estimate put upon the performance of these ovens, (of which one at the Exposition supplies to the civil and military administration, daily, ten thousand small cakes and loaves,) there enters neither exaggeration nor partiality. The interior of the

oven is constantly neat, and the loaves leave it in a condition as nice as possible; while in ordinary ovens the waste amounts to one loaf in twenty.

"The endless tube, or canal, in which the superheated water circulates, may pass at need through a boiler filled with water. It creates in such a boiler a development of vapor truly astonishing, capable of giving without any additional expense a force of one or two horse-power, which can be employed to operate a kneading machine, or for any other purpose. The furnace occupies but a very small space, and the use of coal dispenses with the immense and highly dangerous accumulations of fire-wood required to maintain ordinary bakeries.

"An important additional consideration, which is to be further taken into account, is the absence of the deleterious influences to which the operatives employed to remove from the ovens in general use the incandescent embers and other results of combustion are exposed; and which are exerted by the excessive heat and the oxides and other gaseous compounds of carbon which are exhaled from the imperfectly burned wood. It is rare that these workmen are not forced to abandon their employment at forty years of age; and if the establishment is large, the necessity of keeping the windows open is an additional cause of insalubrity. I think that in our age which, in a spirit of so laudible humanity, occupies itself so much with the public health, these considerations militate greatly in favor of an apparatus so entirely hygienic.

"Messrs. Joly de Marval, with reason, claim for their invention an applicability to plaster-kilns, to distilleries, to refineries, to field-ovens, to pumps, generators of steam for steam-engines, and to all other forms of industrial apparatus in which it is desired to maintain a regular heat anywhere from 50° to 400° C, (from 120° to 750° F.) In a word, this heat is entirely uniform and inoffensive, and is susceptible of application to all exigencies. It has cost the inventors many years of scientific industrial labors. They have happily succeeded in overcoming all practical difficulties. Resting upon a basis of sure calculation, they perfectly master water superheated to four or five hundred degrees, (750° to 930° F.)

"What is to me the most seducing part of their labor, I find in the tables which give the relation between the temperature and the elastic force of vapor, at degrees of heat which had not been hitherto calculated. To this end they have employed a special form of manometer, which the most simple workman can easily consult in order to maintain the proper operation of the apparatus. I think it may be safely affirmed that industry has been presented in this invention with an element of real importance, and one which will in the future be more and more appreciated."

One remark only remains to be made. As the compensator is added to the contrivance to permit the expansion of the water with the rising of the temperature, it is found practicable, in case of necessity,

to make the apparatus to a certain extent self-regulating, by forming such connections with the piston-rod of the compensator as to cause a jet of water to be thrown into the furnace whenever the heat becomes excessive. The same piston-rod may, also, instead of this, be connected with a signal bell, or other indicator of the state of the apparatus, which may serve to call the attention of the attendant to the necessity of regulating the fire.

II.—FURNACES.

SIEMENS'S REGENERATING FURNACE.

The most valuable of all the improvements in the arts of metallurgy, so far as it relates to the economical and effectual application of heat, is that which is presented in the regenerative gas furnace of Mr. Siemens, of London. This was exhibited in model in the Exposition, and was rewarded with the highest honor in the power of the jury to bestow, the *grand prix*. As the invention is one of the most important of recent inventions in the industrial arts, it comes properly under review in this place, although it belongs to the committee on metallurgy to treat in detail of its uses and its economical value. In the London journal Engineering, for June 21, 1867, is contained an account of this furnace, in which its theory and general construction are so clearly explained as to seem to the present reporter preferable to any original description of his own. It is therefore subjoined.[1] The writer observes:

"There are two distinct principles embodied in the Siemens furnace, viz., the application of gaseous fuel and the regeneration of heat by means of piles of brick alternately passed over by the waste gases and by the gases entering the furnace before their combustion. Each of these principles is an important invention in itself, and capable of a useful application in practice without the other; still, the advantages of the combination of both principles as now existing in the Siemens furnace have given to the whole its great value and excellent economic results.

"The gaseous fuel is produced in a special chamber, called the 'gas producer,' or 'generator.' The latter name, however, is objectionable, on account of its similarity with the name 'regenerator' given to the other vital part of the furnace, the two names having no correspondence of meaning. The gas producer is a brick chamber about six feet wide by twelve feet long, with its front wall inclined at an angle of 45° to 60°, according to the nature of the fuel used. The inclined plane is solid about half way down, and below this it is constructed as a grate with horizontal bars. The openings for introducing the coal into the gas producer are on the top or roof of this chamber, and the air which enters through the grate effects the combustion of the coal at the lowest points of the chamber. The products of this combustion rise and are decom-

[1] A short description of this furnace, accompanied by drawings, will also be found in the report of Commissioner Hewitt upon iron and steel, &c.

posed by the superposed strata; they are, moreover, mixed with a quantity of steam which is drawn in through the grate from a constant supply of water maintained underneath the latter. The steam in contact with the incandescent coal also decomposes and produces hydrogen and carbonic oxide gas, which are mixed with the gases produced by the coal direct. The whole volume of these gases is then conducted to the furnace itself by means of wrought-iron pipes. The gases enter one of the regenerators. The regenerators are chambers packed with fire-bricks, which are built up in walls with interstices and air spaces between them, allowing of a free passage of gas round each single brick. Each regenerator consists of two adjoining chambers of this kind, with air passages parallel to each other, one passage destined for the gaseous fuel, and the other for the supply of atmospheric air required for combustion. Each furnace has two such regenerators, and a set of valves is provided in the main passages, or flues, which permits of directing the gases from the producer to the bottom of either of the two regenerators. The gases, after passing one regenerator, arrive at the furnace, where they are mixed with the air drawn in at the same time, and produce a flame of great heat and intensity within the body of the furnace itself. They then pass, after combustion, into the second regenerator, which forms a set of down flues for the waste gases, and ultimately leads them off into a common chimney. On their way from the furnace to the chimney, the heated products of combustion raise the temperature of the fire-bricks over which they pass to a very high degree, and the gases are cooled more and more the further they proceed through the regenerator. After a certain time, the fire-bricks close to the furnace obtain a temperature almost equal to that of the furnace itself, and a gradually diminishing temperature is arrived at in the bricks of the regenerator proportionate to their distance from the furnace. At this moment the attendant, by reversing the different valves of the furnace, opens this heated regenerator for the entrance of the gaseous fuel and atmospheric air, at the same time connecting the other regenerator with the chimney for taking off the products of combustion. The entire current of gases through the furnace is thus reversed. The cold air from the atmosphere, and the comparatively cold gases from the producer, in passing over bricks of gradually increasing temperature as they approach the furnace, become intensely heated, and when they are mixed in the furnace itself, enter into combustion under the most favorable circumstances for the production of an intense heat. The principle of this so-called regeneration of heat, therefore, consists in storing up the waste heat in one set of fire-bricks, and afterwards making use of that heat for elevating the temperature of the fresh gases introduced for combustion. The action of these regenerators is so perfect that, with a temperature of somewhat about 4000° in the furnace, there is no more than about 300° to be felt at the base of the chimney, the escaping gases having a temperature no greater than is absolutely required for maintaining the draught. The sup-

ply of air from the atmosphere, as required for combustion, is entirely due to the draught of the chimney, but the supply of combustible gases is made independent of it on account of the inconvenience and danger which would arise from a gas pressure below that of the atmosphere in the gas mains or pipes. The consequence of such an under-pressure or partial vacuum in the gas-pipes would be the influx of air through all leaks and fissures in the joints of the gas-pipes, and this would lead to a premature mixture of the air with all the combustible gases, with a waste of fuel, and, in some cases, would even cause dangerous explosions. It is, therefore, desirable to maintain in the gas-pipes a pressure slightly exceeding that of the atmosphere. In the majority of cases this effect is produced by placing the gas producers at a considerably lower level than the furnace itself; the gases being at a temperature of 300° to 400°, and consequently of less specific gravity than the outer atmosphere, are forced through the tubes by gravitation, and maintain a slight surplus of pressure, due to the difference of weight of the column of heated gases and of an atmospheric column of equal height. Wherever the placing of the gas producers at a lower level is impracticable, Mr. Siemens obtains the same result by sending the gases up a vertical pipe to a height of some twenty or thirty feet, and then through a horizontal pipe of considerable length for allowing the gases to cool in their passage, and from which they descend again through another vertical pipe. The gases in the down flue are colder than those in the upcast, and they therefore give the requisite difference of weight in the gaseous columns necessary for that purpose. Mr. Siemens has carried out this arrangement at his Model Steel Works, in Birmingham, and it works very successfully. In Sweden, Mr. Lundin has recently proposed and even patented an arrangement for cooling the gases in the flues of the Siemens furnace, by means of a spray of cold water injected among them. M. Lundin, by these means, at the same time effects a purification of the gases from solid matter carried along mechanically, and from certain gaseous combinations which are absorbed by water. These latter gases in some instances are sulphurous acid and other noxious substances, and the purification therefore may, in some instances, and with certain kinds of fuel, become of great value to those who use the Siemens furnace. It is doubtful, however, whether Mr. Lundin's improvements can substantiate a valid patent, since Mr. Siemens has, in some of his specifications, described the cooling of his fuel gases by water, although, perhaps, not with the intention of washing and purifying these gases from mechanical and chemical admixtures.

"This is the present state of this beautiful and important invention. It has supplied us with the power of maintaining an exactly regulated temperature in a furnace of any required size and shape; it has made us practically independent of the quality and nature of the fuel used for producing the required heat from the most moderate up to the very highest temperature. It has reduced the expenditure for fuel to a very

great extent, and it has given us one of the greatest desiderata in so many metallurgical operations, viz: a *clean* furnace, free from ashes, dust, and dirt, and perfectly suitable for the working of the more refined and purified materials which modern industry has produced and is still constantly improving upon. We have further to name as an important feature of the Siemens furnace, the possibility afforded by it of changing the nature of the flame at will, by altering the relative proportion of air and gas admitted through the flues. A surplus of oxygen in the mixture will produce an oxidizing flame, and will give all the corresponding effects upon the materials exposed to its action. By the admission of a surplus of gas, on the contrary, the flame can be made of a reductive character, and used accordingly for deoxidation. In metallurgy, and particularly in the treatment of iron and steel, this is of the utmost importance. There are already several new modes of manufacturing steel direct from the pig iron, patented and practically carried out in France and in Germany, wherein the Siemens furnace is made use of as an indispensable condition for their success. The exhibition contains a collection of samples of very fine steel made by Mr. Berard's process. This is called '*acier à gaz*,' and is made in a Siemens furnace direct from pig iron. Mr. Berard constructs a Siemens furnace with the bottom formed into two separate parts, each hollowed out like a dish, and with a bridge between them upon which the pigs introduced into the furnace receive a preliminary heating. The flame is maintained with a surplus of oxygen, and a quantity of pig iron is melted in one of the chambers or dishes. The oxidizing action of the flame decarburizes and refines the pig iron, and, after a certain time, a second quantity of pigs is thrown into the second dish and melted there. The flame is now reversed in its direction; the oxidizing flame is made to enter at the side where the fresh pig iron is placed. In passing over this, and oxidizing the carbon, silicon, and other impurities in the iron, the flame loses its surplus oxygen, and becomes of a neutral or, at least, only slightly oxidizing character. In this state it passes over the other bath of molten iron, now partly refined, and it continues to act upon the impurities without attacking the iron itself. At a certain moment this portion of iron is completely converted into steel, and that part of the furnace is then tapped so as to make room for a fresh charge of pigs in that place. After that, the current of gases is again reversed, the second bath now entering into the position previously taken by the first, and so the process is carried on continuously with two portions of iron, one freshly introduced and acted upon by the oxidizing flame, the other partly converted into steel and exposed to the neutral flame passing away from the first. Mr. Berard states, that by protracting his process, and by adding spiegeleisen, he can remove sulphur and phosphorus from the iron, and make steel from inferior pigs. Such statements, however, have been so frequently made by inventors, without having been borne out by facts in actual practice, that we must be cautious in accepting them.

"Messrs. Emile and Pierre Martin, of Sireuil, have also commenced steel-making in a Siemens furnace. They melt a quantity of pig iron, and introduce wrought-iron scrap, puddled steel, or other malleable iron into the mass while exposed to the oxidizing influence of the flame. They have produced steel of excellent quality by this method, and are now about to introduce their process into several steel works in France. The great advantage obtained by them, and one which has not yet been arrived at by the Bessemer process, is the conversion of old iron rails and similar articles into steel. That this is a great desideratum—particularly at this present moment of transition of the permanent way from iron into steel—is well known, and attempts have been made by Mr. Bessemer, Mr. Adamson, and several others, to effect the same thing in the Bessemer converter. The first trials, although they proved the possibility of converting old iron rails into steel in that manner, gave an unsatisfactory commercial result. It was found that the rails required to be heated to a white heat before being introduced into the converter, that no more than one-third of such rails could be added to the proportion of two-thirds of every graphitic pig iron, and, with all this, that there was a greater waste in the converter, and more "scull" in the ladle, than with pig iron. Messrs. Martin, on the contrary, are able to use a proportion up to two-thirds of old rails to one-third of pig iron; they can manage the fusing very completely, and without excessive waste, and with a moderate consumption of fuel, advantages which are all due to the Siemens furnace which they employ."

The Siemens furnace was patented several years ago, but it seems at first to have been looked upon with some distrust and to have been received with hesitancy. Of its introduction, the writer above quoted remarks:

"The first manufacturers to avail themselves of the new furnace were the glass-makers. The British plate glass works, at St. Helens, Messrs. Lloyd and Summerfield, of Birmingham, and Messrs. Chance Brothers, Birmingham, were, we believe, among the first who introduced the Siemens furnace in their works. For purposes of metallurgy, greater difficulties and prejudices had to be surmounted. Some of the steel-makers on the continent led the way. Mr. Mayr, of Leoben, in Styria, we understand to have been the first to introduce the new furnace for crucible-steel making, on a large scale. In this instance, the unfavorable position of the Styrian Iron Works in regard to the supply of mineral fuel, was the principal inducement to apply gas in the steel-melting furnace. The gas is made in Mr. Mayr's works, from lignite, which cannot be directly applied for melting steel, as the heat of it, when burnt on the grate, is not sufficient to produce the high temperature required for this operation. Mr. Mayr erected ten gas furnaces, and they have proved a complete and perfect success, enabling him to make crucible cast-steel by means of the cheap and very inferior lignite which exists in his locality.

"For puddling iron and steel, the Siemens furnace was also first applied on the continent in localities where fuel is scarce, or of inferior quality, and of small heating power. In England the reheating of iron and steel blooms seems to have been among the first applications of the Siemens furnace. Messrs. James Russell and Sons, of Wednesbury, the Elswick Works, and the Mersey Steel and Iron Works, were among the first licensees of Mr. Siemens. In Sheffield, Messrs. Naylor, Vickers and Co., Messrs. Thomas Firth and Son, and Messrs. Cammell and Co., took up the gas furnace for melting steel and for reheating the blooms and forgings and within the last two years the Siemens furnace has been adopted in all the larger Bessemer steel works in the kingdom. Mr. Siemens has also erected a small experimenting steel works of his own in Birmingham, of which we gave a notice some time ago. In France the Siemens furnace is gaining ground with equal rapidity. The Imperial arsenal at Lorient, Messrs. Emile and Pierre Martin, in Sireuil, and several other steel makers, have had Siemens furnaces in successful operation for several years; there are many more recently erected in other works, such as Messrs. Verdier's steel works, at Firmini, and there are now twenty furnaces in course of erection under Mr. Siemens's own superintendence at the Creuzot Works."

A recent very important application of the Siemens furnace has been made in the crystal or flint glass works of St. Louis, in the department of the Moselle, France. In this case, a modification has been introduced by Mr. Didierjean, the director of the works, which has rendered it possible to conduct the manufacture in open crucibles, an important point which, nevertheless, it has been hitherto impossible to secure with any fuel but wood. At present, in this great establishment, which turns out daily sixteen tons of flint glass, and employs sixteen hundred workmen, and one hundred or one hundred and fifty artists, the Siemens furnaces are used with no fuel but coal, and the meltings take place in open crucibles.

The disadvantage heretofore experienced in working in this manner, has been the liability of the metallic base of the glass to become discolored by contact with reducing gases. No expedient hitherto tried could remedy the evil; and hence, as a matter of necessity, the materials have been melted in retorts or in covered crucibles. The modification of form of the Siemens furnace which has removed this difficulty, is one by means of which the carbonic acid formed by the combustion is caused, in consequence of its superior specific gravity, to roll over the crucibles and to form a protecting cushion between them and the lighter, which are the reducing gases. The crucibles occupy the circumference of the floor of the furnace, the gases are introduced into the furnace through vertical passages opening nearer the middle. The reducing gases enter on the interior side and the oxygen on the exterior; when the flame reflected from the roof turns downward, it is prevented by the cushion of carbonic acid from touching the materials in the crucibles, which thus maintain all their purity and produce a crystal of the highest brilliancy.

The specific gravity of the crystal of St. Louis is 3.37 This great weight is due to the quantity of lead which it contains; it much exceeds in this respect the crystal of Paris and its vicinity, and also that of England. This crystal refracts light much more powerfully and is much more brilliant in every respect than any other at present manufactured.

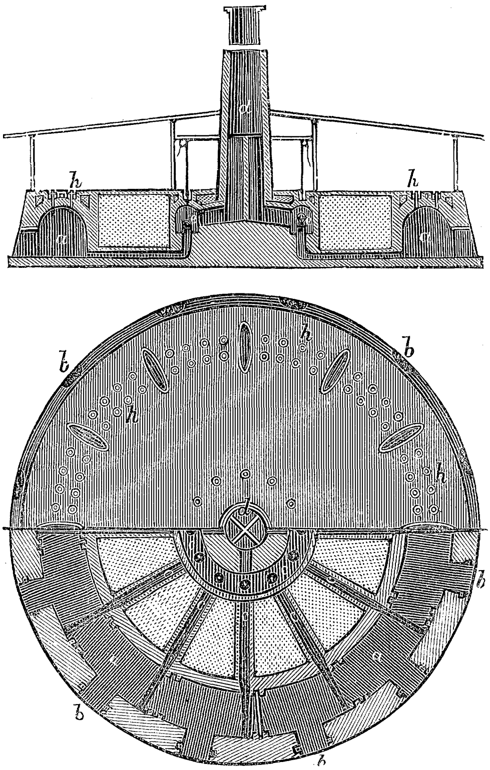
HOFFMANN'S ANNULAR BRICK FURNACE.

The annular furnace for burning brick, invented by Mr. Frederick Hoffmann, of Berlin, which presents one of the most admirable arrangements for promoting efficiency and economy ever introduced into any branch of industry, was exhibited in several beautiful models. This furnace has already come extensively into use in most European countries, and it is impossible to examine the principles of its construction, and to become acquainted with its mode of operation, without being satisfied that it is destined to supersede all other ovens, furnaces, or kilns, wherever brick-making is carried on as a manufacture, and not merely for some temporary and local purpose. It will require but a few words to explain the general plan on which this furnace is constructed. A large annular chamber, with proper openings at the sides to permit the introduction or withdrawal of the articles to be burned is constructed with a central chimney and with removable divisions for separating the annulus into different parts. If, now, we suppose the annulus to be filled with unburnt bricks, and that heat is applied to one division, the smoke or hot air escaping from that division will be employed to dry the bricks in the next compartment before it finally escapes to the chimney. The compartment thus dried will be the next one burnt, and the air required to maintain the combustion in the burning compartment will be made to enter through openings among the bricks last burned, whereby those bricks are rapidly cooled and the air by means of which the combustion is maintained is heated. The coal, instead of being burned on a common grate, is introduced in the form of dust through small orifices provided for the purpose, and closed with plugs all around the top of the annular kiln, and the fineness of this dust is so adjusted to the height of the oven that it is consumed by entering into combustion before it reaches the oven floor. Each compartment of bricks or other objects is thus burnt in its turn, and so the process goes on continuously, the waste heat of the burning compartment continually drying the compartment before it, and taking all the heat of the compartment behind through the medium of the heated air. The figure here presented illustrates the arrangement.

The letters *a a* mark the circular vaulted furnace into which the bricks to be burnt are introduced through the doors *b b*. Flues or passages, *c c*, lead to the circular chamber or drum *e e*, surrounding the central chimney *d*. Valves of cast iron *f f*, close at pleasure the orifices of the channels *c c*. Movable sluices *g g*, formed in the thickness of the dividing walls, enable the different radial chambers to communicate or stop communication between them; *h h* are plugs through which the coal, in

a state of powder, is introduced into the compartment undergoing calcination. In this furnace there are twelve compartments, of which only two will be separated by the sluices, in one of which the new bricks will be in the act of being placed, and from the other the burnt bricks will be in the act of being withdrawn. The whole of the materials in the other compartments will either be heating the air entering to maintain the combustion in the active part, or will be being heated by the hot air which passes off from the active part on its way to the chimney. The necessary changes in the direction of the currents of air are made by raising or lowering the valves, and the action of the furnace is thus rendered continuous, the materials being continually fed into one compartment and withdrawn from the other. The advantages of this furnace lie in its great economy of fuel, amounting, it is said, to two-thirds of that usually consumed in common furnaces. There is also greater equability in the heat, and the articles are more gradually heated and more gradually cooled. There is no smoke generated, and the fuel is burnt while falling by gravity to the bottom of the furnace. Such furnaces are useful for roasting ores or cement, or for baking fine pottery, as well as for burning bricks.

Fig. 83.



Hoffman's Annular Brick Furnace.

Another advantage consists in the fact that the progress of the operation may be easily inspected in all parts of the mass exposed to the heat while it is going on, and the degree of heat may be increased or diminished at pleasure, preventing any danger of injury or loss from overburning or from under-burning.

These furnaces are likely to come largely into use in manufacturing ornamental terra cottas for house fronts, as in cornices, friezes and lintels, as well as for statues, vases, fountains, &c., to be used as rustic embellishments of landscape gardening.

The statement of the inventor that the saving amounts to two-thirds in respect to fuel is confirmed by the results of experience in the use of

the Hoffmann furnaces in England. From these it appears that the saving is even greater than he claims. At the works of Mr. Betty, at Kensington, the following represents the comparative cost to the proprietor of brick per thousand, by the old and new methods of burning. These numbers are given in the Practical Mechanic's Journal of October 1, 1865, by the superintendent of the works:

Cost of production of one thousand brick.

	Old brick-kilns.			Hoffmann furnaces.		
For wages	£0 1s. 6d.				£0 0s. 6d.	
For coal, 10 cwt.	7 10½			2 cwt.	1 7	
For loss	1 0					
Total	10 4½	=$2 50			2 1	=$0 50

Giving a ratio of economy as one to five.

The following is the result of observations made at Durham by Mr. G. Furness:

Comparative cost of production of 222,000 brick in old-fashioned Scotch brick-kilns and in Hoffmann's furnaces.

	£ s. d.	$
Scotch furnaces—17 tons 14 cwt., at 15s. the ton	£59 15s. 5d.	=$289 29
Hoffmann's furnaces—27 tons 12 cwt., at 12s. 6d. the ton	17 5 0	= 84 70
Difference	42 10 5	= 204 59

Giving a ratio of economy as one to three and four-tenths.

Such results as this, added to the very superior quality of the brick obtained by this process, are sufficient to insure the general adoption by manufacturers of this exceedingly important improvement. Already, more than four hundred Hoffmann furnaces are in operation in Germany, and about thirty in England. A single establishment in Vienna, that of Mr. Henry Drasche, employs nineteen of them, having each a capacity to produce eight million of brick per annum. Mr. Drasche employs forty-five hundred workmen, and turns out annually one hundred and ninety-eight milllion of brick; but, besides this, he produces a vast multitude of objects of ornament in terra cotta, designed for the decoration of buildings and grounds—a class of works very favorite in Austria, both for their beauty and for their cheapness.

Mr. Drasche exhibited one of the most attractive collections of bas reliefs, statues, vases, architectural and other ornaments in the Exposition; all of them formed in terra cotta. His display was as remarkable for the great number of beautiful objects which it contained as for the taste with which they had been designed. They were bought up by

visitors with eagerness, and only a few weeks had elapsed after the opening of the Exhibition before nearly every object in the whole collection bore the mark which, in all quarters, grew more and more familiar every day, "sold." All these beautiful productions were baked in the Hoffmann furnaces of Mr. Drasche's establishment.

CHAPTER XII.

ARTIFICIAL PRODUCTION OF COLD.

General observations—Useful applications of cold—Freezing mixtures—Reduction of temperature by evaporation—Artificial production of ice—Carré's sulphuric acid freezing apparatus—Carré's ammoniacal freezing apparatus—Cost of ice produced in this form of apparatus—Carré's continuous freezing apparatus—Useful application of refrigerating apparatus—Twining's American ice machine—Economy of production of ice by Twining's apparatus.

I.—GENERAL OBSERVATIONS.

The importance to the arts of industry and to the promotion of human comfort of being able to control temperatures, as, for instance, in an apparatus, in an apartment, or, in fact, in any given space, large or small, is too obvious to need illustration. As respects the higher temperatures, it may, indeed, be said that without the power to create such temperatures artificially, and to carry them to a degree of elevation immensely superior to any which nature, under ordinary circumstances, anywhere presents over the habitable surface of the earth, the industrial arts as now understood could not exist, and civilization itself would be impossible.

The useful applications of cold are less numerous and less obvious. In most climates, in fact in nearly all beyond the limits of the tropics, cold is regarded rather as an enemy to be repelled, than as an ally to be courted. Its most familiar applications are to check or prevent the putrefaction of organic substances, or to subserve the uses of luxury. For neither of these purposes is it usually necessary to secure a temperature very greatly depressed below that of the ambient air. Nor, if it were so, would the means of accomplishing the object be generally within the reach of those who would desire to profit by them. To command a superior temperature is easy. Combustion furnishes heat in quantity practically exhaustless, and though skill may be of use in securing its economical production or application, none whatever is necessary in order to set the process in operation. But the means of creating artificially a temperature extremely depressed are neither simple nor familiar, and to employ them successfully at all requires a species of knowledge and a degree of scientific skill which are rarely found except with the experimental chemist. There are certain industries, however, of which the process of refrigeration forms a part, which do not require a temperature inferior to that which prevails in the atmosphere, or in the running waters of the earth at the same time.

The ideas conveyed by the words cold and hot are related to our senses merely, and not to anything absolute in the condition of bodies. It is a familiar experiment to place upon the table three vessels of water, one of them at the temperature of freezing, another as hot as the hand can bear, and a third at the temperature of the weather. The experimenter at first immerses one hand in the hot fluid and the other in the cold; after the lapse of a minute or two he places both together in the water of mean temperature, and he is conscious at once of the paradox of perceiving the same liquid to be apparently both hot and cold at the same time. In the working of a steam-engine the condenser supplied with water from natural sources is cold relatively to the steam to be condensed. For all ordinary distillations the natural temperature furnishes sufficient refrigeration.

For certain purposes the natural temperature of the colder season suffices, but not that of the warmer. For such, to a limited extent, it is practicable, by careful contrivances, to preserve the winter temperature throughout the year. This is done by collecting ice in the season of its abundance, and storing it away in magazines with non-conducting walls, sunk usually beneath the surface of the earth. It is by means of ice thus preserved that the low temperature required in refrigerators for domestic uses is maintained; and such ice furnishes also the essential element in the most simple and best known of freezing mixtures—that which is employed by confectioners—a mixture of ice-powder and common salt. This mixture produces a depression of temperature nearly 18° C below that of freezing water. It is the temperature which was adopted by Fahrenheit as the zero of his thermometer.

The cause of the cold produced by freezing mixtures is to be sought in the absorption of heat which accompanies the transformation of bodies of every kind from the solid to the liquid state. This heat becomes latent; that is to say, it does not raise the temperature of the substance into which it passes. On the contrary, when the substances mingled are such (as for the purposes of a freezing mixture they must be) as when in union to remain liquid at a temperature much below that at which they solidify when pure, they will, in liquefying, draw upon their own sensible heat and upon that of bodies in contact with them for the latent heat necessary to their liquefaction; and it is thus that they produce the refrigerating effect from which they derive their name. Saltpetre and common salt, or saltpetre and sal ammoniac, added to three times their weight of water, will depress the temperature of the solution 22° C. If to this solution be added once and a half as much sulphate of soda as of either of the salts previously used, the temperature will sink three or four degrees lower. Equal parts of carbonate of soda, nitrate of ammonia, and water will produce a depression of 32° C. And three parts of phosphate of soda with two of nitrate of ammonia and a little more than one of water, will sink the thermometer nearly 40° C. This depression of temperature is to be understood only of the solution

itself, on supposition that it draws no heat from the substances in contact with it. The latent heat of liquefaction for a given weight of material liquefied is but a determinate amount. When, therefore, a solution is employed as a means of refrigerating other things, the degree of cold will be less considerable in proportion as the quantity of matter to be chilled is greater. And in general it will be found that the useful effect produced will not be sufficient compensation for the trouble and expense of the operation, if it is proposed to apply the process on a very large scale.

As heat becomes latent whenever a body passes from a solid to a liquid state, so a much larger amount is similarly absorbed when a liquid becomes a vapor. There are a large number of liquids, moreover, which evaporate so freely as to produce a very sensible degree of cold without any special arrangements to favor this result. If one hand be moistened with water while the other remains dry, the moistened hand will be very perceptibly colder than the other. If the fluid used to moisten the hand be alcohol instead of water, the sensation will be much more marked; and if, instead of alcohol ether be substituted, it will soon become intolerable. A current of air blowing upon the moistened surface will accelerate the evaporation and increase the intensity of the cold. And a removal or diminution of the atmospheric pressure upon the surface of the liquid will have a similar effect. Pressure and variation of pressure exercise indeed a most marked influence upon the formation of vapor. The particles of most liquids are constantly tending to assume the gaseous form. To a certain extent this tendency is efficient at every temperature to which observation has been carried; but there are two causes by which it is usually held more or less in check, viz: the force of cohesion and the pressure superincumbent on the surface. This tendency diminishes, it is true, as the temperature is more depressed; but with none of the more volatile liquids, nor even in the case of water, has there been experimentally found a point at which it wholly ceases to exist, or at which the fluid becomes absolutely fixed. Evaporation goes on from the surface of snow at the temperature of 0° C, in the open air and in a perfectly still night, at the rate of nearly thirty grams, or about an English ounce, per square metre of surface exposed per hour. At the zero of Fahrenheit, 32° F below freezing, evaporation goes on at the rate of something like seven and a half grams per square metre per hour; and even at —32° F it continues still to be sensible, amounting to not less than a quarter of a gram per square metre per hour. Trivial and insignificant as this slight evaporation may seem, it nevertheless, when extensive surfaces are considered, produces large effects. At the extremely low temperature last named, there rises hourly, from every acre of surface exposed, more than a kilogram of water in the form of invisible vapor; and from every square mile between six hundred and seven hundred kilograms, or from thirteen hundred to fifteen hundred pounds. The elastic force of the vapor thus formed

increases with the temperature. When this force is equal to the pressure of the atmosphere evaporation is attended with ebullition, an effect produced by the escape of bubbles of vapor formed beneath the surface of the liquid. In this state of things there is nothing to prevent the whole mass of the liquid from bursting into vapor in the same instant, except the necessity of drawing from the surrounding matter the large amount of heat which is necessary to constitute its latent heat of elasticity. This requires time, so that ebullition is a continuous process. Under the ordinary pressure of the atmosphere at the earth's surface, water boils at 100° C, or 212° F. In passing into vapor at this temperature it absorbs, without any elevation of its own sensible temperature, an amount of heat sufficient to raise the same weight of water without vaporizing it 537° C, and this is the measure of the latent heat of steam. If we could suppose a quantity of water enclosed in a cavity which it should entirely fill, but could not burst, to be heated up to 637° C, and then allowed vent, this liquid in its escape from its confinement would issue, not in a vapor formed by ebullition, but with an instantaneous explosion like that of gunpowder. The temperature would at the same time fall at once to 100° C.

Under a pressure less than that of the atmosphere, ebullition takes place at a lower temperature. Were two-thirds of the atmospheric pressure removed, water would boil at ordinary summer heat. A vessel of water placed under the receiver of an air-pump, which is then exhausted of air, speedily enters into ebullition; but, unless the machine is kept constantly in action, the vapor which is thus formed will restore very promptly the pressure upon the surface which has been removed by the exhaustion. If, however, the pump is powerful enough to carry off the vapor as fast as it is formed, and is steadily worked, the heat which the rising vapor withdraws from the water will presently reduce the temperature to the freezing point, and the liquid will be converted into ice.

The mode of preparing ice in Bengal, which is mentioned in every elementary book on physics, has been explained by attributing the depression of temperature to evaporation. This mode consists, as is well known, in exposing water in shallow vessels by night beneath the clear skies of India to the open air. A large plain unobstructed as much as possible by trees or buildings, is selected for the purpose, in which pits or excavations twenty or thirty feet square and two feet deep are sunk, the floors being covered with dry stalks of corn or sugar cane. Upon these are placed the water vessels, constructed of porous earthen ware, and not much more than an inch deep. In the morning, if the sky has been clear, the vessels are found to contain thin plates of ice, which are carefully gathered and stored away. This process was successfully imitated in England in the latter part of the last century by Dr. Wells, author of the Essay on Dew; and soon afterward an attempt was made in France to employ it for the systematic manufacture of ice, but the undertaking proved to be economically a failure.

The cold produced in the circumstances here described is in a measure owing to the evaporation of the water, and it is for the purpose of promoting this evaporation that the vessels employed are formed of an earthen ware which is exceedingly porous. Similar vessels have been used almost from time immemorial in Egypt, in India, and in southern Europe, to hold the water used for summer drinking, which they maintain at a temperature refreshingly cool, in consequence of the continual evaporation from their surfaces of the water which exudes through their pores. But evaporation is not the most important agency in the production of the ice collected in this way by the Hindoos. Evaporation may go on no less rapidly when the sky is obscured by clouds, and yet in that case there will be no formation of ice. The same negative result will follow in the clearest nights, unless the air be tranquil as well as clear, though wind accelerates evaporation to a marked degree. It is the loss of heat by radiation into open space, which, in the absence of the sun, is constantly going on without compensation, which, more than any other cause, determines the congelation. This suggests the importance to the success of the process of the excavations in which the vessels are placed. In these the air at the earth's surface, which is always under such circumstances colder and therefore denser than that above, is retained at rest as a liquid is held by its containing vessel, and prevented from mingling with the warmer air, as it would otherwise do under the influence of light atmospheric currents. Strong winds, however, prevent the air from stagnating even in deep valleys; and hence, on windy nights, the process of natural freezing in summer fails; yet on windy nights evaporation is greater, and on still nights it is less, than the mean in the Indian ice pans, other things being equal; the check which, in the last case, the process receives, being consequent upon the saturation of the air stratum which rests upon the water.

Radiation, liquefaction, and evaporation are then the three causes by which the temperature of bodies may be depressed. To these may be added the rapid dilatation of elastic fluids on a sudden reduction of pressure. A striking illustration of this last effect is furnished in a hydraulic machine at Chemnitz in Saxony, described in most elementary books on physics, in which air is highly compressed in a closed reservoir by means of a column of water. If a stop-cock in this reservoir be suddenly opened, the expanding air rushing out produces a degree of cold sufficient to freeze the drops of water which it brings along with it into pellets of ice.

To take advantage, however, of any of these means of producing cold for any useful purpose, and upon a large scale, is not a problem by any means easy of solution. To congeal water by its own evaporation under the air pump, with no means of removing the vapor as it forms except the action of the pump itself, is not practicable unless with such proportions between the barrel of the pump and the receiver as are not conveniently realized. The result is reached with more facility if some

expedient be resorted to for absorbing the vapor as rapidly as it is produced; and this is practicable by introducing into the receiver such substances as have a great affinity for water, as, for instance, anhydrous chloride of calcium, or concentrated sulphuric acid. It was by the use of sulphuric acid that the congelation of water by its own evaporation upon the air pump was first experimentably shown to be a possibility. The experiment is due to the late Professor Leslie of Edinburgh, having been made by him in 1810. It is easily repeated by placing a vessel of thin material, partially filled with water, upon a light support beneath the air-pump receiver, while within the same receiver is arranged a considerably larger vessel containing the concentrated acid. Both the liquids should present a comparatively broad surface. On working the machine the exhaustion proceeds with sensibly the same rapidity as in a vacuum, the vapor being taken up by the acid instantaneously. The water enters almost immediately into ebullition, and in a very short time becomes solidified into a mass of porous ice. This interesting experiment has remained almost down to the present time among the curiosities of the scientific lecture-room, without leading to any practically useful application. In the present Exposition, however, we have seen it employed, with only a modification of the form of the apparatus and of the dimensions of the essential parts, in such a manner as to produce ice in considerable quantities and at a very cheap rate. The apparatus is exhibited in action by Mr. Edmond Carré, of Paris, whose brother, Mr. Ferdinand Carré, exhibits also much more powerful contrivances for the same purpose, deriving their efficiency from a different principle, which will be presently described.

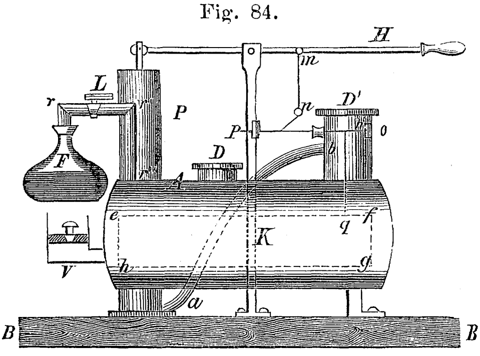
II.—ARTIFICIAL PRODUCTION OF ICE.

CARRÉ'S SULPHURIC ACID APPARATUS.

Mr. E. Carré's sulphuric acid apparatus is shown in its essential parts in the accompanying figure. Its use is to produce the *carafes frappées*, frozen decanters, so frequently seen in Paris. It consists of a large vessel, resembling the boiler of a steam-engine, which is designed to contain the concentrated sulphuric acid; of an air pump with tube connections to be adapted to the wide mouths of the *carafes*, and of a mechanism by which the lever of the air-pump is made to keep the acid in continual agitation. The great volume of the acid renders the loss of absorptive power by dilution very slow, and the constant agitation prevents the formation of a superficial dilute stratum, which, in the ordinary experiment, interferes materially with success. The apparatus is easy of management and does its work very rapidly. With that exhibited, twelve or more flasks containing a pint of water each were frozen in presence of the public in three minutes. The acid continues to act well till it becomes diluted to the fiftieth degree of Baumé's hydrometer, which corresponds to a solution containing two parts of water to three

of the strongest hydrated acid. If, therefore, the reservoir contains originally one hundred and fifty pounds of the concentrated acid, it will only require to be charged anew after having absorbed one hundred pounds of water in the form of vapor. The evaporation of such a mass of water would cause an absorption into the latent form of as much heat as is given out by the conversion of five hundred and seventy pounds of water, taken at 60° F, into ice. An apparatus constructed on this scale should therefore theoretically furnish this same amount of ice at the temperature of freezing before any change of the charge of acid becomes necessary. Practically, however, the production will be considerably less, since a sensible amount of heat will be drawn from the substance of the vessels containing the water, and furnished by radiation from surrounding objects. Allowing seventy pounds for the loss from this cause, we might put the productive power of the apparatus, before renewing the acid, at a quarter of a ton. The acid holder required for an apparatus of this magnitude will be about thirty inches in length and fifteen inches in diameter internally. It is constructed of a material which resists the action of the acid, being chiefly lead, but containing a slight alloy (five or six per cent.) of antimony.

Fig. 84.



Carré's Sulphuric Acid Freezing Apparatus.

In the annexed figure A denotes the reservoir of acid; F, a *carafe* or flask of water connected with the apparatus by the tube *r r′ r″* having a stopcock at L. P is the barrel of the air-pump, and H its lever, which, by means of the connections *m n*, causes the agitator *e f g h* to oscillate. The rod *p p′*, which forms the axis of motion, passes into the cylinder D′ through a stuffing box. At D is seen another shorter vertical cylinder which is closed at top by a glass plate fitted on air-tight. This is to afford an opportunity of examining the interior of the apparatus while it is in action.

Though this contrivance was employed in the Exposition for no other purpose but to freeze water in bottles, it is evident that by adopting such a form of vessel as should permit the ice to be extracted from it, as for instance a vessel cylindrical or conoidal in shape, with caps ground on, it might be made more generally useful. The inventor estimates the cost of production at six centimes per kilogram, which is about half a cent a pound. This estimate supposes, however, that the sulphuric acid undergoes only a moderate depreciation of value in consequence of its dilution. For many purposes its usefulness is not at all impaired; though to restore it to its originally concentrated condition would be attended with considerable expense.

The apparatus in the Exposition was worked by hand. If constructed on a large scale and kept in continuous operation, it would require some form of motor to drive it.

The inventor constructs several sizes of the apparatus, at prices increasing with their power.

	Francs.
No. 1. Apparatus without lever pump and with 1 flask	120
No. 2. Apparatus without lever pump and with 2 flasks	150
No. 1. Apparatus with lever pump and with 8 flasks	700
No. 2. Apparatus with lever pump and with 12 flasks	900

Mr. Carré will furnish also still larger models to order, up to a capacity of one hundred kilograms per hour.

The sulphuric apparatus of Mr. Edmond Carré will not, however, compare in importance with the larger and greatly more complicated contrivances of his brother, Mr. Ferdinand Carré, for the same purpose, which were exhibited in a building erected expressly for them in the park of the Exposition. This machinery throughout the continuance of the Exposition was constantly producing huge blocks of ice, not merely congealed but depressed in temperature at the same time many degrees below the freezing point. The efficient cause producing cold in this apparatus, as in the other, is evaporation; but the liquid employed is ammonia, a substance which is not only vastly more volatile than water, but under ordinary atmospheric pressure, is, in fact, permanently gaseous. Gaseous ammonia is reduced to the liquid form by pressure; but at 20° C (68° F) it requires a pressure of not less than eight and a half atmospheres to produce liquefaction, and at 25° C (77° F) not less than ten. Thus the pressure required rises very rapidly with the temperature. On the other hand, to liquefy ammonia by cold merely, under the ordinary atmospheric pressure, requires a reduction of temperature down to 38°.5 below zero of the Centigrade thermometer. Ammonia, therefore, evaporates very rapidly even at temperatures extremely low; and as the latent heat of its vapor is great, being estimated at 514° C, it may be used as a powerful means of producing cold, provided any practicable method can be devised for removing the vapor as it is formed. To do this mechanically would require a pump of large dimensions; and inasmuch as considerations of economy as well as of health and the comfort of the operators would require that the vapor should be reduced by compression to the liquid state, the pump should be capable of exerting a pressure of from seven to ten atmospheres. If, therefore, it were only by mechanical means that ammonia could be condensed, this substance could not be profitably used as a means of producing cold. But the property which water and some other substances possess of absorbing ammoniacal gas in great volume and with singular rapidity, furnishes a means of condensing it without the necessity of employing any mechanical power. By taking advantage of this property intense cold may be produced with very simple arrangements. The fact was first illustrated by

Faraday in 1823, and it has been a familiar lecture-room experiment ever since. Chloride of silver, at low temperatures, absorbs many times its volume of dry ammoniacal gas. At 60° F, ($15\frac{4}{9}$° C) the absorption amounts to more than forty volumes. But at the temperature of 100° F ($37\frac{7}{9}$° C) this gas is entirely expelled from the compound. If now a quantity of the chloride which has become saturated with ammonia at 60° F, or lower, is placed in the closed end of a strong glass tube bent at an angle, or in the form of an inverted siphon, and if the other branch be freed of air by slightly warming the compound, and the tube be afterwards hermetically sealed, then by heating the mass of chloride up to 100° F, or above, the whole of the ammonia may be driven from it, while, supposing the other arm of the tube to be at the same time immersed in a refrigerating bath, the pressure produced will cause the gas to take the liquid form. This experiment, which is not an unsafe one, provided the tube be of moderate dimensions, allows the progress of the condensation to be observed. The liquid formed is seen to be colorless, very fluid, and with a refracting power superior to that of water. Its specific gravity is stated by Faraday at 0.76. If, now, after the gas has been all driven over, the extremity of the tube containing the chloride be immersed in the refrigerator, and that containing the liquid placed in a vessel of water, the liquid ammonia will immediately commence boiling and will continue to boil until the whole has disappeared, the chloride re-absorbing the vapor as fast as it is formed; and in consequence of the intense cold created by this rapid evaporation, the water surrounding the tube will be converted into ice.

But this material could not be economically employed in producing artificial cold. A given quantity of chloride of silver would produce only about the thirtieth part of its bulk of liquid ammonia, and a fifth part of its bulk of ice at 0° C. In order to produce a kilogram of ice, it would be necessary to employ twenty-seven and a half kilograms of the chloride; and this supposes the operation to be conducted with no loss. Water, on the other hand, dissolves, at moderate temperatures, seven hundred times its volume of the gas, a quantity capable of producing two-thirds of its bulk and half its weight of liquid ammonia, and of converting into ice more than three times its own bulk. A kilogram of water employed as a solvent of ammoniacal gas will thus suffice to produce three kilograms of ice.

In speaking of quantities of heat as transferred from one body to another, or in comparing the quantities of heat absorbed by different bodies, or yielded up by them in undergoing changes of temperature, it is convenient to fix upon some determinate quantity as a unit of reference. By common consent, the amount of heat required to raise the temperature of a kilogram of water, taken at 0° C of temperature, one degree Centigrade, an amount which is also very nearly constant whatever be the initial temperature, has been adopted to serve as such a unit. To this unit the French have given the name *calory*, and the convenience

of the term is securing for it general adoption and use with the physicists of other countries. Instead of the kilogram and the degree Centigrade, English writers have been in the habit of employing the pound avoirdupois and the degree of Fahrenheit's thermometer; but the two units are easily convertible into each other, and this latter mode of computing is at present going out of use.

It may thus be stated that the latent heat of a kilogram of liquid ammonia is equal to ninety *calories*. The latent heat of a kilogram of its vapor, that is to say, of ammoniacal gas, amounts to five hundred and fourteen *calories*. The latent heat of water, liberated in the act of congelation, is equal to seventy-nine *calories* per kilogram; so that one kilogram of ammonia would be capable by its evaporation of freezing six and one-half kilograms of water taken at the initial temperature of zero; or five kilograms taken at the temperature of 24° C, (75°.2 F.)

CARRÉ'S AMMONIACAL FREEZING APPARATUS.

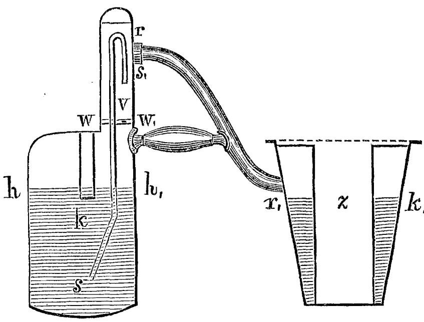
Mr. Carré constructs two forms of apparatus for freezing in which ammonia is the efficient instrumentality. One of these is intermittent in its action, and the other continuous—that is to say, this latter form furnishes an uninterrupted supply of ice at a determinate rate per hour; or if applied to produce cold for any other purpose, it absorbs per hour a given number of *calories*, while the duration of its operation is capable of being extended at pleasure.

The intermittent apparatus is represented in the annexed figure. In its principle and in its mode of use, it is but a reproduction of the experiment of Faraday with the bent tube described above. The difference is only in the form of the apparatus, and in the substitution of aqua ammonia in place of chloride of silver saturated with ammoniacal gas. In the figure herewith presented, the two extremities of Faraday's tube are shown to be replaced by a boiler and a refrigerator. This model is designed only for operations on a small scale; the largest producing at each operation but two kilograms of ice, and the smallest only half a kilogram. It is therefore moderate in dimensions, and portable in form. An apparatus to produce two kilograms of ice would require the evaporation of two-fifths of a kilogram or four hundred grams of liquid ammonia. As this requires twenty times its own weight of water to form a solution of the necessary strength, the capacity of the boiler must be such that it will conveniently receive eight and a half kilograms of the solution—that is to say, it must hold at least eight and a half litres, or two gallons and a quarter, of liquid. But, as the rapidity of the operation is promoted, especially when the freezing is going on, by exposing a large surface of water to the ammoniacal vapor, Mr. Carré, in the earliest forms of this apparatus, made the boiler of at least twice the dimensions required to contain the quantity of fluid employed,

and fixed within it a series of flat shallow basins, with openings in the middle, by which each could overflow into the one below. When the solution was introduced at the top, these vessels were successively filled by such overflow; and thus the solution was divided into a number of strata, with a free space between. A different expedient, to be mentioned presently, has more recently been adopted, rendering it unnecessary to employ a boiler greatly exceeding in capacity the volume of the solution. If we allow twelve litres of capacity to a boiler designed to receive eight and a half litres of solution, there will be abundance of free space; and the quantity of solution may be sufficiently increased above the exactions of theory, to compensate for all losses. Such a boiler would have eighteen centimetres of diameter and forty of height—say seven and a quarter inches by sixteen.

The refrigerator requires to be constructed so as to present a large surface toward the vessel containing the water to be frozen. It is formed of an outer shell in shape slightly conical, with a cylindrical receiver within. The annular wedge-shaped space between the cone and the cylinder forms the condenser which is to contain the liquefied ammonia. The cylindrical cavity in the interior is intended to receive the vessel containing the water. This vessel should fill the entire cylinder so far as convenience will allow, and the remaining space should be filled by some liquid not liable to congeal and having a low specific heat. Alcohol fulfils this condition, though there are saline solutions which are cheaper but absorb more heat. In some of his refrigerators, Mr. Carré introduces what the figure does not show, a succession of little conical shaped receivers within the condenser, which form a row of collars round the cylindrical inner wall, so arranged as to fill successively with the condensed liquid, and thus to present a larger evaporating surface when the refrigerating process begins.

Fig. 85.



Carré's Ammoniacal Freezing Apparatus for families

The boiler and the refrigerator are connected by a tube which receives the liberated gas at the top of a cylindrical dome surmounting the boiler. This appendage is designed to allow opportunity for the steam which rises along with the gas to become condensed, and to return again to the boiler in the form of water, which in great measure it does. The connecting tube enters the refrigerator near the top also. To give steadiness and strength to the apparatus an intermediate brace is introduced between the boiler and the lower part of the connecting tube; and this serves conveniently as a handle.

After what has been said, the mode of employing the apparatus hardly

requires description. There are necessary a suitable portable furnace, and a large tank to serve as a condensing refrigerator. This tank is to be filled from any natural source with water at the ordinary temperature. The boiler charged with the solution is placed over the furnace, and the apparatus is first "purged"—that is to say, cleared of air. This is done after the temperature of the boiler has been somewhat raised, by turning a stop-cock (not shown in the figure) which allows the air to pass off as the gas set free by the heat fills successively the different parts of the apparatus. The expelled air is conducted by a tube into a vessel called the "purger," where it is discharged beneath the surface of water. Any ammonia which may pass over with it is dissolved by the water and saved. When the purging is complete, the stop-cock is closed, and the temperature is steadily raised until the thermometer connected with the boiler indicates 130° or 140° C, at which latter temperature hardly a trace of ammonia will remain in the solution. The refrigerator, which during this time has continued to be immersed in the tank, will now contain the ammonia in a liquid form; and as the temperature of the water bath will probably be not far from 20° C, the tension of the vapor will be about eight or eight and a half atmospheres. The apparatus at this stage of the operation is to be removed from the furnace, and the boiler to be placed in its turn in the water bath. The temperature of the boiler will rapidly fall, and as it does so, the power of the water to absorb ammoniacal vapor will be restored. The gaseous ammonia will be rapidly redissolved, reducing the pressure upon the liquid, which will evaporate with corresponding rapidity, drawing for its latent heat upon the sensible heat of the water to be frozen. The result will be, the complete evaporation of the liquefied ammonia, and the restoration of an aqueous solution in the boiler, of the original strength. The vessel containing the water to be frozen, and the alcohol which is to surround it, should be introduced only after the first part of the operation has been completed. They may otherwise have their temperature raised by the development of heat which occurs during the condensation of the ammonia, and this would involve, so far as it goes, a needless loss. During the congelation the refrigerator must be surrounded by a non-conducting envelope, in order to protect it against radiation, and to secure it from receiving heat from the air.

What capacity should be given to the tank will depend upon whether or not the operation is conducted with the advantage of an unfailing water supply from a natural source. If that is the case a tank of moderate dimensions will answer the purpose; provision being made for constantly renewing the supply of cold water, as that which has become heated in the process is withdrawn. But if the tank is to be charged once for all, and to be used from beginning to end without change of the water, then its size must be considerably increased. We may easily calculate, in the present instance, what quantity of water it ought to contain. The water of the bath may be assumed to have originally a tem-

perature of 17° C (62°.6 F.) It must be sufficient in quantity to absorb all the heat withdrawn from the ammonia during liquefication and from the boiler during the congelation, without having its own temperature raised above, say, 25° C.

The ammoniacal gas condensed comes over at a temperature varying from 20° C to 140° C, say, at a mean, 80° C. The temperature after condensation should not exceed 20° C. Hence it must lose 60° C of sensible heat, and as the capacity of the gas for heat, compared with water, is only 0.508, it transfers by such depression thirty calories per kilogram to the water of the tank, or for two-fifths of a kilogram, twelve calories. The latent heat for the same quantity of liquid will amount to two hundred calories, (in round numbers,) and the whole will be two hundred and twelve calories. Supposing the same bath used to chill the boiler, we shall have to cool down eight kilograms of water from 140° C to 25° C, say 115°, and also to absorb once more the two hundred calories of latent heat evolved by the gas in dissolving in the water. To this must be added the heat given up by the metal of the boiler itself. If we suppose this metal to weigh five kilograms, which is a large allowance, it will be equivalent to increasing the weight of water to be cooled by half a kilogram, since the specific heat of iron is only about one-tenth of that of water. We shall have then 115° $\times$ 8.5= 977.5 calories for the cooling, and to this we must add two hundred calories for the re-solution of the gas, making in all 1,177.5 calories.

The gas dissolved will come over at a temperature varying from 20° C to — 10° C, which will be at a mean 20° below the ultimate temperature of the bath; but the gain from this cause will be slight, amounting only to four calories and may be neglected. Uniting the results, we shall see that the total amount of heat to be abstracted by the bath is 1,389.5, say 1,390 calories. As we take the water originally at 17° C, and suppose it not to have gained in the end a higher temperature than 25° C, (which is an advance of 8°,) the number of litres of water that we need will be found by dividing 1,390 by 8, which will give 173.75, or, reduced to gallons, about thirty-eight gallons. Of course, without much loss, we may allow a larger change of temperature to the bath. A bath of twenty gallons would do nearly as well, and would have an ultimate temperature of less than 33° C, (about 91° F.) An allowance must also be made for inevitable losses by radiation and conduction, so that an apparatus designed to produce two kilograms of ice at an operation should have a theoretic capacity equal to something like two and a half.

The prices at which Mr. Carré furnishes the different styles of this apparatus are not exactly proportional to their capacity. The larger styles are proportionally cheapest. For an apparatus of the capacity of a kilogram at an operation, complete in all its parts, including furnace, tank, ice-holder or freezer, envelope and two thermometers, and delivered in Paris packed for transportation, the price is 282 francs, or about $56. For one of double this capacity, similarly complete, it amounts only to 406 francs, or about $81.

The cost of ice produced in this way Mr. Carré puts at from three to five centimes, according to the price of coal. We may make the calculation for the case of the apparatus of two kilograms which we have been considering. We have to heat eight kilograms of water and five kilograms of iron from 17° C to 140° C, say through a range of 123°. This demands one thousand and forty-five calories. We have also to supply two hundred calories in latent form to the gas set free, and to raise this also in sensible heat from the original temperature of 17° C to a mean temperature of 80° C, which will require thirteen calories more. The total amount of heat which the apparatus will necessarily draw from the furnace will be, therefore, only one thousand two hundred and fifty-eight calories. As a kilogram of coal furnishes eight thousand calories,[1] about a sixth part of a kilogram, or one-third of a pound avoirdupois, would furnish all the heat needed. A ton of coal costs us six or eight dollars—more usually the latter sum. One third of a pound of coal, at eight dollars per two thousand pounds, would cost a cent and a third. This exceeds Mr. Carré's estimate, and it leaves out of account the prime cost of the apparatus and that of the ammonia. Moreover, it is to be considered that a fire cannot be made in a furnace eight or ten inches in diameter, and maintained for an hour and a half (the duration of the operation) with the consumption of only this small amount of coal; and that of the heat which the furnace generates a very large proportion—certainly more than half, and probably four-fifths—passes off through the flue, or escapes by radiation; so that, in point of fact, the ice produced in this apparatus will cost several cents per kilogram, instead of three to five centimes. The only mode of diminishing this cost would be to have a double apparatus for a single furnace, and to perform several operations successively without extinguishing the fire.

It was observed in the early part of the foregoing description that Mr. Carré's original boilers were provided with a number of shallow basins in the interior, arranged one above the other, in order to present a large absorbing surface of liquid during the process of congelation. He has more recently provided, by a very simple but effectual expedient, to secure an instantaneous absorption of the gas without the aid of this system of basins. The difficulty when the whole body of the liquid was in a single mass in the boiler was, that a very strong solution formed upon the surface, and, being lighter than the water beneath, cut off communication between the gas and the unsaturated water. In the new form of the apparatus the inventor has introduced a diaphragm into the neck of the boiler, by means of which he is able to prevent the

[1] The heating power of different coals is very unequal. That of the long-flame cannel coal, of Coventry, was put by Tredgold at nine thousand five hundred calories; common coal of good quality may be taken at seven thousand; charcoal gives six thousand. This last number is commonly taken to represent the heating power of mineral coal, in order that the error of calculation, if any, may be on the safe side.

gas from descending, in any way except through a tube which, passing through the diaphragm, is continued nearly to the bottom of the boiler. The gas is thus conducted to that part of the liquid which is in condition to seize it with the greatest avidity, and its absorption is correspondingly rapid.

There can be no doubt that contrivances of this kind must be very useful and even economical in countries where ice cannot be collected during the summer. Their usefulness ought not to be measured by the contribution which they make to human luxury, or even to human comfort. They cannot fail, for instance, to be often of great advantage in the laboratories of chemists and in hospitals for the sick; and they must be especially valuable to surgeons accompanying armies in the field.

It is a disadvantage that the operation of the apparatus is not expeditious. For an apparatus of the capacity of a kilogram the furnace operation requires an hour, and the process of congelation another hour. If two kilograms are prepared at once, the time consumed from beginning to end will not be less than three hours.

It is to be observed that along with the gas, during the furnace operation, there passes over, inevitably, some watery vapor, which condenses first into water, and then forms ice in the refrigerator. The amount of ice thus formed is to be counted among the losses; but after the operation is over, it must be reliquified and returned to the boiler. This may be effected by placing the apparatus for a time in a position which will allow the water to flow back through the connecting tube.

CARRÉ'S CONTINUOUS FREEZING APPARATUS.

The two kinds of apparatus above described for producing artificial cold are interesting and have their value; but they cannot be said to possess a great industrial importance. The same is not true, however, of the continuously acting apparatus of Mr. Ferdinand Carré, which is on a much larger scale than either, and is, in fact, one of the most valuable contributions which science has yet made to the promotion of human comfort, and to the progress, in certain forms at least, of industrial art. Indeed, when the apparatus is examined in its details, and the ingenious felicity with which the difficulties involved in the problem have been met is understood and appreciated, this invention cannot fail to be recognized as presenting one of the most admirable illustrations of the combination of scientific knowledge with practical skill which the Exposition presented.

This, therefore, is the proper place to claim for America the credit of having originated an invention so beautiful and so useful; and which, however much it may have owed to the enterprise and skill and to a certain extent to the genius of Mr. Carré in achieving for it a commercial success, was nevertheless patented many years ago, both in England and in the United States, and was subsequently constructed, in a form embracing all the essential features of the apparatus of Mr. Carré, by our

countryman, Professor Alexander C. Twining of New Haven. In the apparatus actually constructed by Professor Twining the volatile liquid employed in refrigeration was sulphuric ether; but his patent covered all volatile liquids, including ammonia and carbonic acid; and the differences between it and that which we are about to describe are only such as the differing properties of the two substances naturally suggest. For purposes of comparison, Professor Twining's apparatus will be more fully described further on. The material for the description has only come into the possession of the writer since his return to this country, while this account of the invention of Mr. Carré was prepared in Paris in the summer of 1867.

Mr. Carré's continuous process, like the intermittent, depends then for its efficacy upon the evaporation of liquid ammonia. In both processes the liquefaction is effected in substantially the same way. Aqua ammonia is introduced into a boiler, and the gas is expelled by heat into a condenser; but in order that the process may not be arrested by the exhaustion of the solution, the impoverished liquid is gradually withdrawn from the bottom of the boiler, while a corresponding volume of a fresh and strong solution is constantly flowing in at the top. The condensation is produced by the united effect of cold and pressure. From the condenser, the ammonia in a liquid state passes on to a refrigerator, in which are placed vessels containing the water to be frozen; and as the boiler and the condenser keep up an unfailing supply of the liquid, so the refrigerator will continue to freeze successive masses, so long as the proper temperature is maintained in the boiler. The ammoniacal vapor which leaves the refrigerator is redissolved to form the rich solution which is to supply the boiler; and the water of solution is the same which was previously withdrawn exhausted from the boiler itself. Thus, as there is nothing added to the contents of the apparatus, and as there is no escape of any part of them by leakage or otherwise, the same materials go on indefinitely producing a uniform effect, the measure of which is expressed by the number of calories which the apparatus is capable of absorbing in an hour. Mr. Carré constructs five models of this form. The power of the smallest of these corresponds to an absorption of twelve hundred calories per hour, and that of the largest to one of twenty thousand calories. The space occupied by the several parts of the apparatus is, for the smallest, twelve square metres (one hundred and thirty-two square feet;) and that required by the largest fifty-five square metres, or nearly five times as much. The boiler required for the smallest is about one metre high and thirty centimetres in diameter For the largest, the corresponding dimensions must be two and a half metres in height and eighty centimeters in diameter. The cost of the largest, packed and delivered in Paris, with all the accessories complete, is thirty-six thousand francs, and of the smallest about seven thousand. The largest will produce two hundred kilograms per hour and the smallest twelve. The first requires the labor of three attendants and the other of only one.

In order that this ingenious and somewhat complicated apparatus may be better understood, the following description of its several parts is presented in detail.

Plate VI contains a representation of the apparatus, taken for Mr. Pouillet in the workshop of the constructor. This apparatus was designed to produce one hundred kilograms (two hundred and fourteen pounds) of ice per hour. In this plate Fig. 1 represents the front elevation, and Fig. 2 is an end elevation. Fig. 7 gives the view from above and furnishes an idea of the plan. Figs. 3, 4, 5, and 6 represent on a much larger scale, but still only about one-eighth of the actual size, the most important subordinate details. In both the elevations and in the plan the same letters are constantly used for the same parts.

The boiler containing the aqueous solution of ammonia is distinguished by the letter A. It is exposed to the heat of the furnace B to about one-half its vertical altitude. The solution should never stand higher than this; and at C is placed an indicator to show its exact level. This indicator is simply a glass tube placed vertically, and communicating with the boiler both at top and at bottom.

At the summit of the boiler is a tube extending upward, with a branch through which the liberated ammoniacal gas is conducted to the large *liquefier* J. Above the branch, the tube is contracted, and at the top it carries a safety-valve with its lever and weight. If at any time this valve is lifted, the ammonia, instead of escaping in the air, is forced to pass down through the small pipe E into a vessel containing water, E′. At F is seen the tube which feeds the boiler with the saturated solution of ammonia brought back from the *absorbing apparatus* UU, to be presently described.

The upper half of the boiler G G, is occupied by a contrivance called the *rectifier*, which consists of a series of broad and shallow vessels, pierced with holes in the manner of sieves, through which the solution introduced through F falls in a trickling shower till it finally reaches the mass of the liquid in the boiler. Each alternate basin has a large opening, H, in the middle, but extends at its circumference so as to meet the walls of the boiler in which it forms a partition. The intervening basins are free at their circumferences but without central opening, and are suspended from those above them. The object of this is to expose many times successively the ammoniacal gas arising from the solution in the boiler to the shower produced by the trickling from basin to basin of the liquid introduced by F. This takes place necessarily as the gas passes alternately from centre to circumference and from circumference to centre in rising. The effect is to free the gas in great measure from the watery vapor which accompanies it at first; this vapor being almost entirely condensed by the liquid which it encounters, and which is at a much lower temperature than itself. A secondary advantage is gained also by this arrangement, in that the liquid which enters through F at a temperature comparatively low, say 70° C, receives from

the vapor which it condenses a large accession of heat, and to the same extent reduces the charge upon the furnace.

The gas thus freed from vapor passes, as stated above, through the tube I to the liquefier JJ, which consists of a combination of numerous zig-zag and spiral tubes immersed in a tank of cold water; the water being constantly renewed from an unfailing source in communication with Z, which is a distributing recipient designed to supply different parts of the apparatus. At the point where the tube I meets the liquefier there is a kind of box, K, into which I opens, and from which there proceed three distinct tubes, which, after making four or five turns in the refrigerating water of the tank, terminate in a corresponding box, K′, at the bottom. Arrived at K′ the gas will be reduced to a temperature of 20° to 25° C—say 70° to 80° F—and under the pressure of ten atmospheres, more or less, which is constantly maintained in the boiler, it is at this temperature reduced to a liquid state. In this condition it passes through the tube L to the vessel M, which is the regulator of efflux. This is a very important part of the apparatus. It forms the dividing barrier between the space in which there prevails a constant pressure of ten atmospheres and another where the entire efficacy of the contrivance depends on the maintenance of a pressure greatly lower, which, in fact, shall never exceed an atmosphere and a half. And while doing this it must at the same time permit the liquid ammonia to flow freely from the first of these spaces to the second, and prevent it from flowing more rapidly than the successful conduct of the operation requires. To understand in what manner and how simply it effects all this, attention must be turned to Fig. 6. This figure represents a strong air-tight cylinder of cast iron of about eight inches in internal diameter and fourteen in internal height. Within this is a hollow cylinder, *n*, made of very thin metal, so as to be buoyant. This is open at top but closed at bottom. The external cylinder has a prolongation downward in the direction of its axis, being in form a tube of about one inch in diameter. Toward the lower extremity of this prolongation, the interior bore is reduced and made very truly cylindrical. The inner cylinder has a similar prolongation of less diameter, which at the lower extremity is enlarged and turned so as accurately to fit the reduced portion of the outer tube. The accuracy of this joint is important. It ought to be tight enough to prevent the escape of a liquid through it, but should not obstruct movement by excessive friction. The internal cylinder is maintained in a vertical position, free of contact with the outer one, by means of a central guide represented at the top at *p*, which is fixed to a bar crossing the mouth of the cylinder. This cylinder is represented in its lowest position resting on a stud *p′* at the bottom of the small prolongation. In this position it will be seen that a perforation made through the walls of the joint just spoken of forms a communication between the tube *m′* and the interior of the cylinder. But if the inner cylinder be lifted slightly, the perforations in the two parts of the joint

will cease to correspond and communication between *m′* and the interior will be cut off.

The tube *m* at the top of the apparatus is the tube which is connected with L coming from the liquefier. It is here that the liquid ammonia flows in. There is a little plate or fender fixed to the inner cylinder at *o* opposite the tube *m*, the design of which is to prevent the liquid from flowing immediately into the inner cylinder and to direct it into the space between the two. In consequence of this arrangement the light inner cylinder will presently be buoyed up by the inflowing liquid and will rise so as to obstruct, as just described, communication with *m.′* It is prevented from rising further than is necessary for this purpose by a stop represented on the guide *p*. As the influx of liquid from *m* continues, the annular space between the two cylinders will presently be filled up, and the liquid overflowing into the inner cylinder will soon after so increase its weight that it will once more settle into the position represented in the figure. There will then be a discharge through *m′*. Should the discharge be more rapid than the supply, and should the inner vessel maintain permanently this lower position, there would arrive presently a moment when all the liquid having passed, the uncondensed gas would begin to enter the refrigerator; an occurrence which would vitiate the result. There would arise at the same time the more serious danger that the pressure existing on the side of the boiler would be established in the refrigerator also. But these evils are prevented by the automatic action of the apparatus; for so soon as the level of the liquid in the inner cylinder has descended about half way, the vessel becomes too buoyant to preserve its position. It therefore rises and shuts off communication with *m′* a second time. It will be seen that the guide *p* must be so constructed as not only to maintain the inner vessel in the vertical position, but also to prevent its rotation; and it will be quite evident that the inequality of pressure in the two spaces between which this joint is interposed cannot sensibly interfere with its action.

The liquid having left the regulator through the pipe *m′*, passes by the tube N to the cavity P, which is called the *distributor*. On its way this tube is conducted through the enveloping tube O, the use of which will be explained further on, but which is not an indispensable part of the apparatus. This enveloping tube is wound round the tube T, through which the vaporized ammonia is returning from the refrigerator QQ. These vapors, being very cold, serve to reduce the temperature of the liquid in N, before it enters the refrigerator.

The refrigerator itself consists of a number of zigzag or spiral tubes—in the apparatus here represented, six in all—immersed in a tank constructed of non-conducting substances. These zigzags return upon themselves six times, forming so many partitions in the tank, between which vessels containing the substances to be subjected to cold may be placed. Each one of the six zigzags receives an equal supply of the liquid ammonia from the distributor. The small tubes conveying this

supply are shown at P, in Fig. 1. The vessels to be refrigerated are sustained by a kind of carriage or slider, which admits of a reciprocating motion, and which receives this motion from the same machine which works the pump employed to return the resaturated solution of ammonia to the boiler. Fig. 7 shows this connection, and the manner of the movement. In this figure the vessels containing the substances to be frozen are marked R. The arrangement of the same vessel as seen from the side is shown under the same letter in Fig. 1. In the same figure is seen, at the bottom of the refrigerator, the large tube S, into which all the zigzags, R, discharge the vaporized ammonia. The whole space in the tank surrounding the zigzags and the vessels marked R is filled with an incongealable liquid, which may be alcohol, but is usually a solution of chloride of calcium.

From S, which is called the *collector*, is seen rising the tube T, which conveys the gaseous ammonia to the cylinder U, passing by the way through the enveloping tube O, where it receives some heat from the liquefied gas which is passing through N to the refrigerator. This vessel U is ordinarily partially filled with water drawn from the bottom of the boiler, from which the ammonia has been in great part exhausted, and which is therefore ready to take up greedily the gas introduced through T. The tube T, as is seen in the figure, extends nearly to the bottom of the vessel, and delivers the gas beneath the surface of the water. At U, on the left, is an indicator of water level, similar to that at C. Within this vessel U is observed a spiral tube. Through this spiral there circulates a current of cold water, entering by the tube *a*, which extends from the reservoir Z to the lower extremity of the spiral, and passing out through the tube *b*, which discharges it into the vessel Y. Near the top of the vessel there is seen also a flat vase V. This is designed to receive the absorbing water brought from the boiler; and its bottom is pierced with holes like those of the vases of the *rectifier* GG, that the water may fall through in a shower, and thus present to the gas a greater absorbent surface.

The water is not brought, however, from the boiler directly to U. In that case it would be too hot to absorb the gas effectually. It passes first through the two coolers X and Y. Into X it is introduced through the tube W, by turning the cock shown at W′. The pressure in the boiler expels it without necessitating the use of a pump. The stop-cock may be set so as to supply very accurately the water in proportion as it is wanted. The vessel X is formed of two concentric cylinders, and between these are two spiral tubes, formed of the tube W continued, and conveying the water drawn from the bottom of the boiler. These spirals are immersed in a liquid filling the annular space between the cylinders, which is the reconstituted ammoniacal solution on its way from the absorber to the boiler. The water from the boiler is hot, and the solution from the absorbent is cold. The two liquids to some extent exchange their temperatures by this contact; and this is, so far as it

goes, an economical advantage in both ways. It promotes this exchange that the two fluids circulate in opposite directions; the liquid from the absorbent entering at the bottom and ascending, while the heated water from the boiler enters at top and descends. From X, the water from the boiler is conveyed in the tube W, still continued, to the vessel Y, where it forms but a single spiral ascending from the bottom to the top, and is refrigerated by the water discharged from the spiral in U, which enters Y by means of the tube *b*. It reaches, finally, by the tube W, still continued, the absorbing vessel U, being received in the vase V, and descending through its perforated bottom in a shower, as above described.

It has been stated that the exhausted water is drawn from the boiler through the tube W, and that the saturated solution from the absorbent is returned through the tube F. The water flows freely, on merely turning the stop-cock W, but some force is required to drive the solution back through F. This force is supplied by a pump *g*, operated by a small steam-engine or other source of power. To prevent any escape of ammoniacal gas from the pump some special provisions are necessary. Such an escape would be not only economically disadvantageous, but would be attended with unpleasant effects to the attendants. The form of the pump employed is shown in Fig. 4, which is drawn to a scale one-eighth of the actual dimensions. In this figure the tubulure *u* is that through which the saturated solution is drawn from the absorbent by means of the tube marked *h* in the general view of the apparatus; and the tubulure *u'* is that by which it is forced through the tube *i* (best seen in the drawing in plan) into the annular space of the vessel X, and from that through F into the boiler. A tube of caoutchouc, marked *v* in the section of the pump, is secured firmly to the upper part of the piston (which is reduced in diameter for the purpose) by means of an iron binding-wire, and surrounds the piston rod, as far as the top of the barrel, where it is turned over and fastened by a plate bolted on as shown. Any gas which might make its way between the packing of the piston and the barrel will thus be prevented from escape at the top, while the elasticity and flexibility of the tube will allow perfect freedom of motion. A second tubulure *u''* communicates with the upper part of the absorbent X, through the tube *h'*, and thus prevents any accumulation of gas above the piston.

Stop-cocks are employed to close at pleasure the principal communicating tubes of the apparatus. These are protected against leakage in a similar manner. Fig. 3 is a section of one of them. The core of the stop-cock is conical, as seen at *q*, and it is kept firmly in place by means of a spiral spring in a cavity beneath it, which cavity is closed by a screw with caoutchouc packing. A tube of caoutchouc surrounds the stem of the stop-cock, which is of some length, and this is bound at the bottom by means of iron wire to a short tube rising from the bulge of the stop-cock of which it forms part, and to the enlarged upper end of the stem

also. This tube is surrounded and protected by a succession of iron rings *t t*, which strengthen it against interior pressure, but allow the stem freely to turn so far as to open and close the cock. Stop-cocks or this kind are placed in the tubes F, W, and N, and a larger one in T.

Fig. 5 represents the distributor P, and is designed to exhibit the manner in which the supply is equalized to the several zigzags of the refrigerant. The letter *w* here marks the junction of the distributor with the tube N, which introduces the liquefied ammonia from the regulator M. The liquid descends through the tube *w′* to the bottom of the distributor. The tubes *x x x*, which rise vertically through the bottom of the vessel, are in communication with the several branch tubes leading to the zigzags, and each of these is perforated with similar holes at equal heights, permitting all to receive equal portions of the liquid as it reaches the common level.

One or two observations further only are necessary. When the operation begins, the whole apparatus is necessarily full of air. This is expelled by means of a simple contrivance called a *purger*. The purger is a cylindrical vessel partially filled with water, shown at *d*, into which descends a tube *c*, from the absorbent U, closed ordinarily by a stop-cock. At the commencement of the operation, the boiler having been charged with a strong solution of ammonia, the cocks are all closed until the temperature of the solution has reached 130° or 140° C, when free communication is established between the different parts of the apparatus, and the cock leading to *d* is also opened. The gas expels the air through the tube *c* beneath the surface of the water in *d*, from which it escapes in bubbles, while the ammonia is retained in solution by the water and may be recovered.

The tubes *e f* are parts of the apparatus not indispensable. The first of these serves to conduct water from the general reservoir Z to the large envelope O of the tubes N and T, and the second is movable, and serves conveniently to fill the vessels R with water designed to be frozen. It is an advantage that this water, in passing through the enveloping tube O, (which for this purpose should have considerable capacity, and should be secured water-tight at its extremities to the tubes passing through it,) will have its temperature considerably depressed in advance by the effect of the cold vapor returning through T.

When the apparatus is constructed upon a smaller scale some of its parts are more simple. If, for instance, there be but one zigzag or spiral in the refrigerator, the distributor may be omitted, and the liquefied ammonia may be conveyed directly from the regulator to the refrigerator.

It need hardly be observed that, after this apparatus has been some time in action, there will be found to have accumulated in the collector S a certain amount of water or ice, formed of the watery vapor which passes over from the boiler along with the ammonia, and which remains behind in the refrigerator because of its inferior volatility. This is from time to time removed by means of suitably arranged stop-cocks.

It will be seen that this apparatus requires a large amount of refrigerating water to maintain at the desired temperature the liquefier and the absorbent vessel, and that it also requires a consumption of fuel, not only to heat the boiler containing the ammoniacal solution, but also to work the forcing pump. The pump may be worked by water power, if such a power is obtainable, or even in small models by hand; but for an apparatus producing more than fifty kilograms of ice per hour, a motor is indispensable.

It is stated by Mr. Carré that for every kilogram of coal burned there are produced from eight to twelve kilograms of ice, according to the dimensions of the apparatus. To manage the larger forms of the apparatus, the services of two men are required, and a motor also is necessary, capable of driving eight hundred and forty litres of liquid per hour into the boiler. The pressure in the boiler must be taken, for the purposes of computation, at not less than ten atmospheres; and as the machines are adequate to the production of two hundred kilograms per hour of ice, they will, within the same time, liberate from solution, liquefy, evaporate, and redissolve forty kilograms of pure ammonia. These data may enable us to calculate the probable cost of production, supposing such an apparatus to be set up in this country.

First, as to the expenditure of heat in the furnace. The forty kilograms of ammonia, with the twenty times forty of water, which are required to dissolve it, give a total of eight hundred and forty kilograms of liquid to be acted upon. At the beginning of the operation this liquid may be at 17° C of temperature, but as, after the mass has once been heated up to the working point, the supplies which return to the boiler are probably never below 60° C, we may consider that for continuous work we have to heat eight hundred kilograms of water from 60° C to 130° C, that is to say, through a range of 70°, and also to convert forty kilograms of liquid ammonia, at the temperature of 60° C, into vapor at 130° C.

The furnace must then furnish to the water fifty-six thousand calories; to the ammonia, in the form of latent heat, twenty thousand; and in the form of sensible heat, one thousand four hundred; in all seventy-seven thousand four hundred calories. This would require the combustion of thirteen kilograms of coal, capable of producing six thousand calories the kilogram, which, at three and a half centimes the kilogram, would cost less than half a franc, or about nine cents. At eight dollars a ton the same amount would cost ten cents and a half. The actual consumption would be considerably greater, but in long-continued operations, and in furnaces carefully constructed with a view to economy of heat, it need not be more than doubled. Supposing an actual consumption of twenty-five kilograms per hour, each kilogram will produce eight kilograms of ice; a result which corresponds with the lower limit fixed by Mr. Carré. Different kinds of fuel differ so much in their heating power that an estimate of this nature cannot be made exact without knowing the

description of fuel to be used. If the coal furnishes seven thousand five hundred calories per kilogram, the production will rise to ten kilograms of ice per kilogram of fuel. And possibly a severe attention to economy in the arrangements of the furnace may effect a sufficient saving of heat to justify Mr. Carré's highest statement.

To the cost of the coal for the boiler is to be added that of the fuel for the motor. This may be estimated by considering the work to be done. Eight hundred and forty kilograms per hour are to be injected into the boiler, against a pressure of ten atmospheres; which, at ten metres to the atmosphere, is equivalent to raising the same weight to a height of one hundred metres. The total work thus performed is equal to eighty-four thousand kilogrammetres per hour, which is about one-third of a horse-power. If we make the force of the motor, for security, half a horse-power, there will be required about a kilogram of coal per hour, practically, perhaps, something more, to keep it in operation. The consumption of fuel on all accounts, per hour, will not exceed, therefore, fourteen kilograms; and if the coal is of superior quality, may fall as low as eleven, at a cost of from nine to twelve cents.

The principal item of current expense in this manufacture will be, however, the wages of the attendants. Two attendants, competent to manage an apparatus of so peculiar a description, could hardly, in this country, be obtained for less than five dollars a day. If the working day extend to ten hours, the cost of attendance will then be fifty cents an hour.

Two hundred kilograms of ice will thus be obtained with an outlay of not more than sixty-two cents, or seven pounds avoirdupois for one cent.

This result keeps out of view, however, the interest on the investment, and the incidental expenses for repairs, for lubricants for the motor, and other minor matters. The influence of these considerations may be appreciated by taking into view the operations of an entire year. If we suppose the apparatus to operate ten hours every day, and three hundred days in the year, the total production will amount to six hundred thousand kilograms of ice per annum. Attendance, at five dollars a day, will cost fifteen hundred dollars per annum. Coal, at one dollar and twenty cents per day, will come to three hundred and sixty dollars per annum. The apparatus, if purchased in Paris and imported without duty, would cost, in currency, ten thousand dollars, and, with the duty on, probably fifteen thousand dollars; on which sum the annual interest, at six per cent., would be nine hundred dollars. If the manufacture were attempted in a city there would be a serious item for rent. We may suppose it to be so situated that the expense on this account need not exceed one hundred dollars a year. These sums united amount to two thousand eight hundred and sixty dollars; and if we allow one hundred and forty dollars for incidental expenses not included in the foregoing, we shall have a total outlay of three thousand dollars to produce six hundred thousand kilograms of ice. This is equivalent to a cent for two kilograms, or a quarter of a cent a pound avoirdupois.

It is presumed in what has been said thus far, that the water, which will be required in pretty large volume to absorb the heat given out during the liquefaction and the re-solution of the gaseous ammonia, will be obtainable without cost. But this is a supposition which cannot be made unless the apparatus is established at some point below the level of an adequate natural source to which no commercial value is attached. If the water has to be elevated by mechanical means, or if it is derived from the public water supply of cities, it will constitute an additional item of expense which will have to be taken into account.

The quantity of water to be provided may be calculated as follows: In the liquefier the gas is received at 130° C, and the liquid is delivered at 25° C. Its sensible heat has to be reduced 105°, and all its latent heat absorbed. The first of these items amounts to two thousand one hundred calories, and the second to twenty thousand calories; in all, twenty-two thousand one hundred calories per hour. Supposing the water of refrigeration to be received at 17° C, and discharged at 25° C, every kilogram will carry off eight calories, and the removal of all the heat will require two thousand seven hundred and sixty-three litres.

In the reunion of the evaporated ammonia with the exhausted water drawn from the boiler, there is a demand for a still larger supply of water of refrigeration. The water is drawn from the boiler at the temperature of 130°, and the solution is effected at that of 25° C. The water on its way to the absorbing vessel exchanges temperatures, to a certain extent, with the regenerated ammoniacal solution. Their difference of temperature is one hundred and five degrees. It is hardly supposable that they reach the common mean. If we suppose that each approaches the mean by one-third of the difference, we shall probably be not far from the truth. The heated water will then enter the refrigerating vessel at a temperature of 95° C, and this must be reduced to 25° C; that is to say, through a range of seventy degrees. Eight hundred kilograms, in falling seventy degrees, will liberate fifty-six thousand calories, which must be taken up by the surrounding water. The ammoniacal vapor coming from the refrigerator will give up, in entering again into solution, its twenty thousand calories of latent heat. This vapor leaves the refrigerator at perhaps —15° C, but it partially exchanges temperatures with the liquid ammonia which is on its way to the refrigerator at the temperature of 25° C. The liquid possessing more than twice the capacity for heat which belongs to the vapor, the former probably descends to fifteen degrees in consequence of the partial exchange, while the latter may rise to five degrees, and at this temperature is delivered into the absorbent vessel. In rising to twenty-five degrees it absorbs four hundred calories, which are to be deducted from the sum of the two preceding numbers. Uniting these results, we find that provision must be made for the removal of seventy-five thousand six hundred calories during the regeneration of the ammoniacal solution. And supposing, once more, that the water employed to convey away this heat does not

gain in temperature more than eight degrees, the total volume required will be nine thousand four hundred and fifty litres. This, being added to the two thousand seven hundred and sixty-three litres required for the liquefaction, will give a total of twelve thousand two hundred and thirteen litres—say, in round numbers, twelve thousand—or three thousand two hundred English wine gallons required per hour, which is equivalent to a constant influx at the rate of nearly a gallon per second. It is evident that the economy of the process will be sensibly affected by the question of water supply.

The production of ice is not the only practical application of the cold-generating apparatus of Mr. Carré. There are many industrial processes, which for their success depend upon the maintenance of a moderately low and steady temperature; and others which are greatly promoted, or which succeed, only when the depression of temperature is extreme. In breweries, and in manufactories of sugar, we have examples of the first class of these applications; and in the concentration of saline or alcoholic solutions, in the crystallization of certain salts, in the determination of certain chemical reactions, and in furnishing more rapidly than it can be done by distillation, fresh water from the ocean at sea, the second is illustrated. But the amount of useful effect which can be obtained from a given apparatus will not be the same in all these varieties of application. This is owing to the varying amount of loss which occurs under different circumstances, but which occurs to a greater or less degree in all. Moreover, where surrounding circumstances remain the same, the amount of loss will be in a measure dependent on the intensity of the cold which it is desired to produce. In the manufacture of ice, the vessels containing the product may be removed as soon as the congelation is complete; but if, for any purpose, it is sought to produce ice of a temperature of ten or fifteen degrees below zero, there will be an increased liability to the invasion of the apparatus at this lower temperature by heat derived from the surrounding air. It is evident that if the ice were not removed at all, and the apparatus were to be maintained in activity for an indefinite time, there would arrive a moment when the accession of heat from without, always increasing as the depression continues in the refrigerator, would just balance the amount withdrawn by evaporation, always diminishing with the same depression. At this point the useful effect of the machine would practically cease. What would be the extreme limit of cold which, under such circumstances, the apparatus would reach, cannot, perhaps, be exactly stated. It would depend very much on the temperature prevailing in the apartment in which the operation is conducted, and on the relative proportions of the boiler and the refrigerator; but in an atmosphere at zero, it might descend to sixty or seventy degrees below.

EXTRACTION OF POTASH FROM SEA WATER BY REFRIGERATION.

The useful applications which have been thus far made or suggested of the apparatus do not, however, require so extreme temperatures as this.

One of the most important of these has been to the extraction of valuable salts of soda and potash from the mother waters left in the manufacture of common salt from the waters of the sea. In the evaporation of sea water by solar heat, the common salt, which is the most abundant of its saline ingredients, is at first deposited nearly or quite pure, and this continues until about four-fifths of the entire amount has been withdrawn from the solution. In the mother water which remains, there is present a mixture of common salt with sulphate of magnesia, and the chlorides of magnesium and potassium. The separation of these salts has heretofore been a difficult operation, attended with large loss, and only partially effectual. The sulphate of magnesia and the chloride of magnesium are of little value, and their presence renders the treatment of the solution difficult. But if these waters are subjected to a temperature of 18° C below zero, there takes place a double decomposition of common salt and sulphate of magnesia, with the formation of sulphate of soda which is deposited in crystals, and of chloride of magnesium which remains in solution. The sulphate of magnesia is thus almost entirely withdrawn from the water, and the sulphate of soda which is obtained, is a valuable commercial product; being the material from which carbonate of soda, the most extensively useful of all chemicals in the industrial arts, is ordinarily prepared. The waters are now subjected to evaporation over the fire, and the remaining common salt which they contain is deposited in the form of the most beautiful fine salt. The chlorides of magnesium and potassium still remain in the solution; but when the concentration has reached the specific gravity 1.31, the solution is allowed to flow over a broad surface of *béton*, where, in cooling, it parts with all the potash it contains in the form of a double chloride of potash and magnesium. The remaining water, containing only chloride of magnesium, is rejected. This double chloride, washed with half its weight of cold water, yields three-quarters of its potash in the form of chloride of potassium; and the remaining quarter, still held in solution in the water used in this final operation, is returned to the boiler. The separation of potash from sea water, thus effected, is one of the most important and valuable results which science has, in modern times, contributed to the industrial arts. Though potash is the most useful of the alkalies, the natural sources from which it is possible to obtain it economically are very few in number. Hitherto the supply has been chiefly derived from the ashes of land plants, from which it is separated by lixiviation. This resource, which continually grows more precarious as civilization advances and as forests disappear, is destined, doubtless, to give way to the process just described, and which has already been for a number of years in active and successful operation in connection with the vast salines of Mr. Henri Merle & Co., at Giraud, on the Mediterranean coast of France. The salines of this company cover ten thousand hectares, (twenty-five thousand acres.) The company have applied the treatment above described to the mother waters derived from the tenth part of this area,

amounting to one hundred thousand cubic metres per annum, with an annual product of four thousand tons of anhydrous sulphate of soda, one thousand tons of chloride of potassium, and twelve thousand tons of refined table salt. The amount of potash salt obtained bears but a small proportion to the other substances, but it is an exceedingly important contribution to the resources of the chemical arts.

One great advantage attending this process is found in the fact that the condition of the waters after leaving the refrigerator is so changed as to prevent the formation of incrustations upon the interior of the boilers, a trouble which in all previous methods of treatment was exceedingly annoying, and sometimes interrupted the operation altogether. This is a consequence of the almost complete decomposition of the sulphate of magnesia during the refrigeration, and the removal of the sulphuric acid in the form of sulphate of soda, while the amount of chloride of magnesium is largely increased. It results that not only is there no formation of the heavy crusts which occur in the boiling of the waters which have not been subjected to this process, but even the slight incrustations which are formed in the refining of mineral salt are not at all seen.

Having stated, just above, the total amount of the various salts which are annually obtained by the refrigerating process of Mr. Carré, as applied to the mother waters of the salines of Giraud, it may be worth while to estimate the cost of the operation. The waters are reduced in temperature to -18° C; and as the process is continuous throughout the year, it may be assumed that their initial temperature is as high as 12° C, perhaps 15° C. Adopting the latter number for the sake of the computation, and assuming that the specific heat of the saline solution, taken according to volume, is not essentially different from that of water, the refrigeration of every litre of the solution will require the removal of thirty-three calories. And as a cubic metre contains one thousand litres, the entire amount of heat to be abstracted from the one hundred thousand cubic metres will amount to the large total of three billion three hundred million calories. This amount requires still to be increased by ten per cent., since it is found necessary to dilute the solution by one-tenth its bulk of fresh water, in order to prevent the deposit of common salt along with the sulphate of soda which it is the object of the refrigeration to obtain. Making the addition, it appears finally that there are three billion six hundred and thirty million calories for the annual absorption of which provision must be made. This is equivalent to the heat produced by the combustion of six hundred and five tons of coal, taken at six thousand calories the kilogram.

We have seen, however, in the discussion of the economy of the large apparatus of Mr. Carré above, that for every twenty thousand calories absorbed in the refrigerator, seventy-seven thousand four hundred must pass into the solution in the boiler; so that, allowing for waste by the chimney and otherwise, we must expect to expend in the furnace at least

six times as much heat as we remove in the refrigerator. It is necessary, therefore, to allow for a consumption of something like three thousand six hundred tons of coal, which, at thirty-five francs the ton, will cost one hundred and twenty-six thousand francs.[1]

There may be, however, a very large saving upon this, amounting to probably a third, effected by causing the exhausted fluid leaving the apparatus to exchange temperatures with the fresh solution entering; and, moreover, this process is not to be charged with the entire cost of the fuel employed in it, but only with the excess of its consumption above that of the process which it has replaced, a point in regard to which information is wanting.

It is probable that the cost of labor and attendance is substantially the same for both processes; so that it may safely be assumed that a great part of the increased production is a clear profit. This increased production is probably more than half the total amount; that is to say, it exceeds six thousand tons of refined table salt, two thousand tons of sulphate of soda, and five hundred tons of chloride of potassium per annum. Against this we have to set off the increased expenditure on account of coal, which is probably but a small fraction of the total value.

OTHER USEFUL APPLICATIONS OF REFRIGERATING APPARATUS.

There are many other useful applications of the refrigerating apparatus of Mr. Carré, which it will suffice to notice briefly. In the first place may be mentioned its employment, which is likely soon to be general, in breweries, to preserve the must of malt from fermentation, or to maintain it during fermentation at a determinate but moderate temperature. It is known that during the warm season the greatest care and attention are often insufficient to prevent great loss from the rapidity of change of the fermenting liquid. Many of the largest European brewing establishments have already introduced artificial refrigeration into their works with entire success and to their great advantage.

The manufacture of sugar, whether from the cane or from beet-root, is attended with constant danger of loss from the great liability of the expressed juice to ferment, with the conversion of its suspended sugar into alcohol and carbonic acid. Slight elevation of temperature promotes this tendency; a high heat along with defecating substances in great measure removes it, but is attended with another danger, viz: that of destroying its property of crystallizing. After the expression of the juice there is always more or less loss from the first of these causes, since the operation necessarily takes place in warm weather; and

[1] In regard to the proportion of useful effect to waste in the refrigerator, it ought, perhaps, to be here remarked that the present is one of those cases spoken of above, in which the exposure to loss of effective power is greater than the average, on account both of the large surface exposed to the air and of the low temperature to which the liquid mass has to be reduced. The estimate given in the text of the amount of fuel necessary, will therefore probably fall below the actual consumption.

during the rapid evaporation which follows there is additional loss from the second cause. It is believed that both of these evils may be prevented by means of artificial refrigeration. In regard to the first there is no doubt; as to the second it is not known how far the experiments which have been made have proved to be satisfactory. When an aqueous solution of almost any kind is subjected to a freezing process, it is observed that congelation begins with the water only, and that the first ice which is formed contains but a minute quantity of foreign matter. The unfrozen portion of the liquid constitutes, therefore, a solution much more concentrated than the first. Now, if from a dilute solution like that of sugar in the juice of the cane it is desired to be rid of the water, two processes present themselves; the water may be expelled by heat in the form of vapor, or withdrawn in the form of ice by the aid of cold. If this last process succeeds without withdrawing at the same time any important proportion of the substance in solution which it is desired to save, it will be on several accounts a preferable process. For, in the first place, it will be a security against loss from the decompositions which occur spontaneously at higher temperatures; and secondly, it will require only about one-sixth part as much fuel to remove a given quantity of water from a solution in the form of ice, when used in Carré's apparatus, that is necessary to convert the same water into steam, and thus to remove it by evaporation. The method of refrigeration is, moreover, free from the danger of in any manner impairing the property of crystallization. Should it be found that it does not remove along with the water a serious amount of the sugar in solution, this process cannot fail to be a valuable auxiliary in this very important manufacture.

The same process has been employed advantageously in improving the quality of wines by concentration, and it is obvious that it is similarly applicable to alcohol, to acids, and to aromatic principles, which are ordinarily separated with injury and loss by distillation.

In the transportation of supplies for the daily markets of large towns, the refrigerating process is destined in the future to be productive of great public benefit. At the present time, cattle, sheep, and fowls are conveyed in vast numbers in closely-packed cars, and in the most sultry weather, for long distances to the points at which they are to be slaughtered for food. Owing to the suffering to which they are subjected, they often reach their destination in lamentable condition. Not unfrequently they are found to be sensibly reduced in their weight by fatigue and insufficient feeding during their transportation; and it would not be too much to affirm that in many cases they fail to arrive in such a state of health as to make their flesh an entirely wholesome food. All these evils would disappear if the animals could be prepared for food at the points where they are raised, and transported to their destination in form to be delivered directly to the consumers. And the additional advantage would be gained that the bulk and weight of the mass to be

transported would be reduced more than one-half. On grounds of humanity, of economy, and of the sanitary interests of the public, such a change, if practicable, is greatly to be desired. In countries where ice is naturally formed in great abundance, there is no reason why refrigerator cars should not be attached to market trains upon our railroads, and kept at a temperature near to zero by a liberal use of this naturally formed ice. It has been suggested that a still more effectual mode of accomplishing the object which this arrangement would be intended to secure, and which, in some instances, it has been actually employed to secure, would be first to reduce the temperature of the meat to be preserved by exposing it for a short time in the apparatus of Mr. Carré, to a temperature about three or four degrees below 0° C, and then, after withdrawing it and enclosing it in a vessel or an envelope impervious to water, to immerse it in the same apparatus, and by a continuation of the process to enclose the whole in a solid block of ice. This might be too elaborate a mode of preservation for the entire supply of a large city market, but for delicacies and articles which have to be transported to great distances it would be well worth adopting. The ice-envelope might be reduced in temperature some degrees below zero, and, placed in a proper refrigerating car, it would long continue to be a perfect protection.

The ventilation of churches, theatres, and all public assembly rooms, during the warm season, is another object to which the refrigerating apparatus of Mr. Carré may be made very beneficially subservient. It is now generally true that during the warm days of summer the outer air is at a higher temperature than that within the building; and this will invariably be the case in structures of masonry, provided the windows be kept open during the night, and are closed at sunrise. Notwithstanding this, a crowded assembly will find it intolerable in summer to sit in an apartment where there is no movement of air. The windows will be thrown open, the warm air admitted, and the assembly will be more uncomfortable than before. Nothing is easier, however, than to introduce into any such apartment a steady flow of air at a temperature of refreshing coolness, by which the hot air shall be expelled and a permanently comfortable atmosphere substituted. To accomplish this desirable object it will not generally be necessary to provide any special system of distribution for the cool air introduced. Our public buildings are, in most cases, already provided with ducts for conveying heated air in winter from furnaces to their several apartments, and the same channels will serve in summer for air artificially cooled. It will evidently be no less easy to control, by means of registers, the degree of depression of temperature in the apartments than it is in the opposite season to regulate the heat. As to the means of transferring to large bodies of air the cold produced by the refrigerating apparatus, they will easily be devised, and may take a variety of forms. A refrig-

erator may be constructed, for instance, on the general plan of that shown in Plate VI, only having the spaces designed for the chloride of calcium solution much narrower and perfectly free. Through these, air may be driven in a perpetual stream by any usual ventilating fan. To prevent any ill effects from cold draughts in a room occupied by a large assembly, the discharge may be made near the ceiling, and the air first delivered into a large receiver, from which it may escape into the room through considerable surfaces of wire gauze.

There is still another useful application of the process of artificial refrigeration in the preparation, on a large scale, by crystallization, of many soluble salts. There are few salts whose solubility is not greatly increased by heat, or which are not to a very large extent, if not entirely, deposited under the influence of extreme cold. Salts which in their solutions would require great concentration in order to effect their crystallization at ordinary temperatures, crystallize at once when the temperature is considerably depressed; and where a manufacture of this kind is conducted on a large scale the operation may be made continuous, and considerable economy may be secured by causing the exhausted water, on leaving the refrigerator, to exchange temperatures with the saline solution which is entering.

Besides the cold-producing contrivances in which the efficient agent is liquefied ammonia, Mr. Carré has constructed machines for accomplishing the same object by means of volatile substances which retain their liquid form under the ordinary pressure of the atmosphere, such as ether. In these, of course, the vapor formed in the refrigerator must be removed by mechanical means, as it is impossible to absorb it, either economically or expeditiously, as is done in the case of ammonia, by means of any solvent. A powerful air-pump is employed, acting at once as an exhausting and a compressing-pump, for the purpose of maintaining a low pressure in the refrigerator, and driving the vapor at the same time into a condensing vessel, where it is made to resume its liquid form, and where it yields up its latent heat to the water in which the condenser is immersed. These machines were not exhibited by Mr. Carré, and are, perhaps, no longer constructed by him. The ammoniacal apparatus offers advantages greatly superior, as will be obvious when it is considered that the latent heat of ethereal vapor is less than the fifth part of that of ammoniacal gas, while its density is more than four times as great; the specific gravity of the two in the liquid state being nearly equal. The specific gravity of ether is 0.72, and that of liquid ammonia 0.76. From these data we compute that in order to produce any determinate effect, to remove, for instance, a thousand calories, a bulk of ether would be necessary nearly five and a half times greater than would be required of ammonia for the same purpose. Thus, in order to absorb one thousand calories, it would suffice to evaporate something less than a litre and a half of ammonia; but if ether is sub-

stituted, more than eight litres will be necessary. The ether apparatus of Mr. Carré is nevertheless very ingenious, especially his very effectual contrivances for preventing the possibility of the slightest leakage through stop-cocks, joints, or stuffing-boxes.

The ether employed by Mr. Carré is the ordinary ether of commerce. Methylic ether, or the ether of wood-spirit, has been used for the same purpose by another inventor, Mr. Charles Tellier, who has constructed refrigerating apparatus for breweries, and for cooling the air of apartments. Though Mr. Tellier's name appears in the list of exhibitors, his apparatus was not present in the Exposition. It is understood, however, to be constructed on principles quite similar to those of the ether apparatus of Mr. Carré. Methylic ether has the advantage over the ordinary ether, called sulphuric, in being greatly more volatile. It exists under the ordinary temperature and pressure of the atmosphere only in the gaseous state, and becomes liquid without increase of pressure at -24° C. At 20° C it requires about four atmospheres for its liquefaction. Mr. Tellier's apparatus was originally constructed with a view to its use on shipboard as a means of obtaining fresh water from the waters of the sea, but it is equally applicable in any situation and to any purpose for which refrigeration is required. It will produce a greater intensity of cold than ordinary ether, and, other things being equal, will operate more rapidly; but it requires, also, a much more powerful pump for withdrawing the vapor from the refrigerator and compressing it into the condenser. In the case of common ether, this pump has to work against a pressure of only one atmosphere; with methylic ether, it must be capable of working against four at least. The machine of Mr. Tellier has been introduced successfully into the great brewery of Bass & Co., at Burton, in England.

Among the contrivances for producing cold artificially, should not be forgotten those which have been from time to time introduced into temporary use, deriving their efficacy from the dilatation of uncondensible gases. The compression of elastic bodies produces heat in amount precisely equivalent to the work which has been expended in the compression. The reverse operation ought, therefore, to be productive of an equal amount of cold. And it is true that it will be so, if the dilatation be allowed to take place so soon as the compression is complete, and before any portion of the heat which has been produced by this compression has had time to escape by conduction or radiation. In this case, however, the effect of dilatation will be to restore the original temperament of the elastic body, and nothing will be gained for purposes of refrigeration. To secure any useful result, therefore, by operating on this principle, it is necessary that the heat of compression should be got rid of before the dilatation is allowed to begin. In this case, the resultant temperature will be below that at which the operation was commenced, and will be further below in proportion as the compression was greater;

but it will not be true that the elastic body will absorb, in dilating, the same amount of heat which it yielded up in the compression. If one hundred cubic metres of air, at the temperature of 20° C, were to be forcibly compressed into one-eighth part of its bulk, its temperature would rise four hundred and ten degrees, and the developed heat would amount to eleven thousand nine hundred calories. But if by artificial cooling, or by abandonment for a sufficient time to itself, this body of condensed air should be brought back to its initial temperature, and then allowed to dilate to its original bulk, it would fall but one hundred and seventy-one degrees, and would lose only four thousand nine hundred and seventy-five calories. Thus, more than half the force expended in the compression is ineffectual for any useful purpose. The loss is greater in proportion as the compression is carried further; but, on the other hand, without large compression, no considerable effect can be produced, unless by employing very large forcing-pumps and very capacious reservoirs, with correspondingly increased danger of loss by conduction and radiation.

The usual mode of employing this system of artificial refrigeration has been to permit the escape of the condensed air, after it has returned to the normal temperature, into a refrigerating vessel charged with a liquid not liable to congeal, in which are immersed the vessels containing the substances to be acted upon. The cooling of the condensed air is in great measure effected during the progress of the condensation, by injecting cold water in the form of spray. One great disadvantage of the process, which will be obvious on a moment's thought, is, that the expanding air will produce a considerable part of its effect in the reservoir in which it was condensed, and will carry over only a portion of it to the refrigerator. But the circumstance which will always prevent its successful introduction as a form of profitable industry, is the comparatively small return which it is capable, under the most favorable circumstances, of making for a given expenditure of fuel. The heat produced by compression is, of course, only the mechanical equivalent of the force employed to compress. Suppose that the whole of this could be made effectual for the object in view; in other words, suppose the apparatus to be capable of absorbing just as many calories as are developed in the compressed air, and that there was none of that large and inevitable loss which we have seen to be the essential condition of applying the machine to any useful purpose at all; let us on this supposition make the computation, what will be the effect of a single horse power, expressed in kilograms of ice produced. A horse-power is equivalent to two hundred and seventy thousand kilogrammetres per hour. A calory is equivalent to four hundred and twenty-four kilogrammetres. A horse-power may then be represented by 636.8 calories, and this number of calories corresponds in amount to the heat set free by 6.43 kilograms of water at 20° C, in becoming ice at zero. It is a steam-engine of the highest class in point of economy which furnishes a horse-power of force without an expendi-

ture of coal exceeding one and a half kilograms per hour. The productiveness of this process cannot, therefore, much exceed four kilograms of ice to the kilogram of fuel, even on the supposition that there is no waste, either necessary or accidental. But the unavoidable losses arising from the necessity of absorbing the heat developed by compression, and from the expenditure in part of the effect of dilatation, within the reservoir of condensed air itself, and not in the refrigerator, will reduce the actual product from one-half to three-quarters; so that it would not be safe to count on securing more than one kilogram of ice for each kilogram of coal consumed, even were the air to contribute to the fluid of the refrigerator all the cooling effect of which, when it reaches there, it is theoretically capable. There is, however, the additional disadvantage to be considered, that the air, being a very bad conductor, exchanges temperatures only slowly with other substances which it encounters, and that as it bubbles through the fluid into which it is discharged, much of its refrigerating power is carried away with it. The production of cold by means of the dilatation of compressed air is not likely, therefore, to become a profitable industry.

An apparatus of this kind was, however, patented in England in 1850, and continued for a time to operate. About the same time a similar apparatus was set up in the city of New Orleans, in regard to the economical results of which the proprietors spoke prospectively with great confidence. But before its capabilities could be fully tested, the building which contained it was unfortunately destroyed by fire, and the experiment is not known to have been renewed in this country.

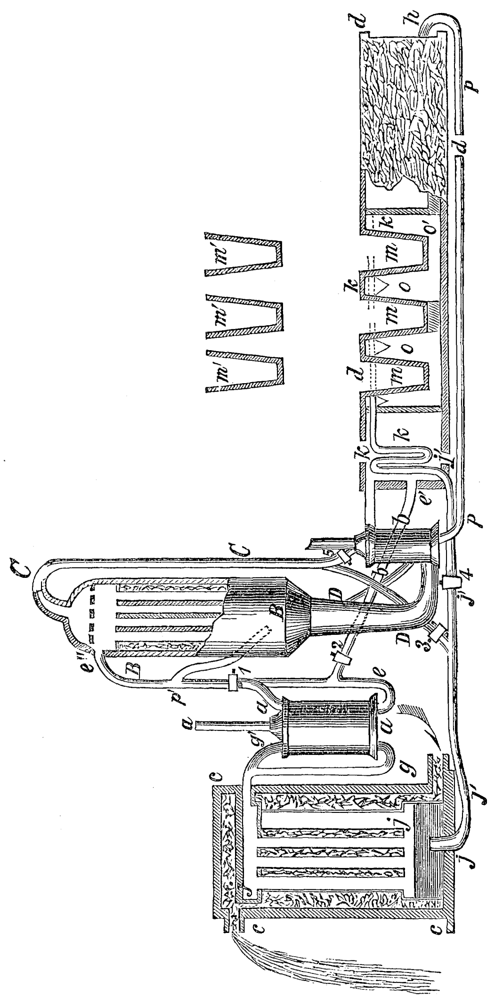
TWINING'S AMERICAN ICE MACHINE.

We return now to consider the refrigerating apparatus of Professor Twining, spoken of above. This is the first arrangement ever invented for the production of ice with economy and on a commercial scale. The possibility of achieving so valuable a result had been demonstrated many years before, and this demonstration was also made by one of our own countrymen. Jacob Perkins, an American in England, celebrated for his inventions, patented in that country an arrangement consisting of a vessel immersed in water from which ether is pumped in vapor into another vessel, and there recondensed by pressure and by the cold of water exterior to the condenser. The restored liquid flows back of itself into the exhausted vessel. Around this vessel ice collects, which must be broken off or otherwise detached. This apparatus was capable of small uses, but was never introduced into practice, so far as is known, even for those.

The invention of Professor Twining was first patented in England on the 3d of July, 1850. The United States patent for the same was issued November 8, 1853, and afterwards extended to 1871. This patent covers, under certain modifications, all the practical machines since operated,

whether in the United States or in foreign contries, by the evaporation and restoration of volatile liquids. It explicitly describes four distinct and simple modes of combination, by means of which an exhaust vessel, a pump, and a condensing vessel, or "restorer," may be applied to manufacture ice in bulk. In all these there is used a freezing cistern, made with water chambers open to the air, and which either hold the substances to be cooled or the separate water vessels containing water to be frozen. The water chambers are simply open spaces conveniently enclosed between thin metal plates, partitions, pipes, &c., which together form channels in which a cold liquid or vapor is made to circulate in contact with the plates of the water chambers, and to freeze through them. The annexed drawing, Fig. 86, sufficiently explains Twining's patent.[1] The cylinder *a a a* is a pump which exhausts, or draws in through its valves and pipe on the side *e e′ e″*, and compresses or forces out on the side *g g′*. The former may communicate as at *e′* with the air-tight exhaust vessel, or cistern, *d d d*, the latter being a box so constructed with thin metal plates and partitions (or equivalent pipes) enclosed in it and united to it, alternately on one side and its opposite, and also at top and bottom, as to form the re-entering spaces or water chambers *m m m*. These also create an open winding way, *o o o*, through the box and between the plates, such that a cold fluid drawn or forced into the cistern through the pipe *p p*,

Fig. 86.



Twining's Apparatus for Refrigeration.

[1] As a single drawing is made to illustrate several different modes of operation, superfluous connections were necessary. Parts not in action must be left out of view in following the modes respectively.

must pass around between and under the water chambers, from end to end, and pass out by the pipe *e′ e*. Water vessels, *m′ m′ m′*, nearly fitting these chambers, may be set into them, and the contact of the two made complete by an uncongealable liquid (salt water for example) filling between the water vessel and the sides of the water chamber. These are the only parts necessary to the first and simplest operation for freezing, which is as follows: A volatile liquid, as ether, sulphuret of carbon, or other, fills in part the channel *o o o*, but leaving room above the liquid for its vapor to pass over through *o o o* to the pump *a a a*, which draws it in. The same pump next forces out the vapor into a coiled condenser, or tubular restorer, *j j j*, surrounded by cold water flowing constantly through *c c c*. This restorer spreads into and discharges in a chamber underneath the coil the vapor condensed therein by cold and pressure. By the pipe *j′ j′ j′*, and through *p p*, connected by a suitable opening and a cock, the liquid is conducted back into the cistern. The cold produced by vaporization in the spaces *o o o*, together with the flow of cold vapor along the water chambers, freezes through the uncongealable liquid and the water vessels. The frozen blocks will become loosened from the water vessels by exposure for a short time to the air, or to water of an ordinary temperature. The blocks actually made by the freezing apparatus have been purely transparent, except at and near the middle, and in size a foot square by six inches thick.

A second mode of operating is to provide a separate exhaust vessel, B B, communicating by the aid of suitable connecting pipes and cocks (as 1, 2, 3, 4) through *e″ p′ p p o o o* and *e′ e* with the exhaust of the pump, and receiving again the restored liquid at the top of B B along *j j j* and the larger return or circulation pipe C C. The pump, in action, will draw cold vapor from the volatile liquid in B B (through *o o o* and *p p′ e″*) in contact with the sides of *m m m*, and freeze water, or cool other substances, in those water chambers. This constitutes, essentially, the operation by expansion and restoration of liquid carbonic acid set forth by Mr. T. C. S. Lowe, in his patent of April 2, 1867.

A third mode of employing the above freezing combination was specified in another patent issued to Twining, April 22, 1862. Preserving every part of his apparatus, as last mentioned, (the cocks 1 and 3 being open, but 2 and 4 closed,) a small circulation pump, *b b*, is added for the purpose of drawing the cold liquid itself out of B B, by the large conduit D D, and forcing it through *p p p* into and through *o o o* around the water chambers, and then returning it to B B through C C. This is the form and operation originally employed at Cleveland, Ohio, in February and March, 1855, with an exhaust-pump of eighteen inches stroke and eight and a half inches bore, capable of producing a ton of ice in twenty-four hours; and which did produce, under disadvantages, six hundred and sixty-one pounds in eleven hours and ten minutes. It was also the publication of these results that first brought the practicability of the ice manufacture to public knowledge.

Still a fourth mode of employing the above-named invention was described in Twining's original patent, and it is the mode which was taken up and employed in England after the publication of the Cleveland results. In this the exhaust vessel B B is supplied with vertical tubes closed beneath, or entering a *cul-de-sac*, allowing the ether to run down and its vapor to escape upward. The vaporized liquid thus abstracts heat from a contiguous uncongealable liquid that surrounds the pipes, and, in its cold state, is drawn out by the pump *b b*, in place of the cold volatile liquid described in the preceding paragraph. The same pump also circulates it in open troughs which contain the water vessels. This modification having been reserved, although described in Twining's patent issued in 1852, was afterward secured to him by another patent issued April 15, 1862.

Finally, a fifth mode of operating—and one of the four first mentioned as being described in the original patent—is the following: independently of B B and *b b* and their connections, the exit pipe *j j j* of the *restorer* is prolonged into *d d d*, in a coil *k k* cooled by exposure to the cold vapor in *d d d*. The same is further prolonged into a "percolator" which, to adopt the language in the patent itself, lies along the vessel (cistern) in or near one of its upper angles. This has certain perforations or perforated branches or channels (see *k k*) girdling every exposed side of each *water-chamber*, and made to inject the ether in jets, or drops, or films, upon or between its exposed surfaces or coatings. The volatile liquid thus spread upon or running down the water-chambers freezes through the *uncongealable liquid* and the *water vessels* in those chambers.

Having thus presented evidence which must be esteemed conclusive that the problem of artificially producing intense cold was first solved practically and economically in America, it may be interesting to add, in the words of the inventor himself, some brief account of the early history of the invention, as given in a statement printed but not published in 1857. He says:

"The first experiments were mere elementary trials, made as far back as the year 1848. By maintaining a vacuum in a small reservoir of ether immersed in water, the weight of ice which the evaporation of a given quantity of ether would produce was proved. Next, by computing the power necessary to effect that evaporation, there was found a sufficiently promising result to encourage a prosecution of the subject. The experiments were repeated, till 1850, under different forms and with accordant results. It appeared that one pound of ether, by its evaporation, was adequate to produce one pound and one-fifth of ice from water of 32° F, besides cooling down the ether 28°.

"The next question arising was whether the ether vapor could be recondensed with sufficient rapidity. By numerous experiments it was ascertained that only two hundred superficial feet of thin copper pipes would form an adequate surface for the manufacture of two thousand

pounds of ice in a day of twenty-four hours, even employing water of the temperature at the earth's equator.

"It was next to be ascertained whether the evaporation itself could be made sufficiently rapid. By trial it was found that one superficial foot evaporated, in a partial vacuum, five and a half pounds of ether per hour, even at the low temperature of four degrees above zero. This wonderful result proved that the evaporation, even at such a low temperature, had proceeded three-quarters as fast as that of water in the boilers of locomotive engines on railroads. In this, as well as in several subsequent particulars upon which the entire practical value of the invention depends, it was found that nature, so far from opposing the theory by difficulties in practice, was far more *kind* than *theory*, by itself, could have ventured to anticipate.

"Again, it had been supposed, prior to these experiments, that the non-conduction of heat by ice would interpose an impracticability in respect to the enormous surface necessary to freeze water in bulk. It was made to appear, however, that a congelation of one-eighth of an inch in thickness could be realized per hour, and that two hundred and forty superficial feet would be a sufficient exposure for one ton of ice per day of twenty-four hours. It was besides ascertained that the rate of freezing was not appreciably obstructed by the thickness of ice already formed.

"The first attempt at a complete freezing construction was made in the summer of 1850. The machine had only capacity to freeze a pail-full of water at one operation. It embraced the evaporating, the condensing, and the freezing parts of the present engine and apparatus. But the mode of applying the freezing power was widely different. Six months were consumed in trials with this machine, and the most discouraging practical difficulties were brought to light. It was not till long afterwards that the inventor could discover the proper modes of obviating these difficulties. Nevertheless, this first small machine served as a complete verification of the facts, principles, and numerous small experiments which had been relied upon; and it thus became an encouragement, in the end, to attempt a vastly larger construction.

"The present engine was in readiness for a first experiment February 15, 1855. It was calculated to produce two thousand pounds of ice per day in ten freezing cisterns of cast iron, each divided into seven water chambers. With only two cisterns of the ten, three hundred and seventy-one pounds of ice were made in eight hours; and, in addition, thirteen hundred pounds of metal were cooled down below freezing temperature; the aggregate result appearing to demonstrate that the machine, with its full complement of cisterns, would be competent to the production of two thousand seven hundred pounds per day, instead of the two thousand for which it was intended. The freezing, however, was too rapid; and the ice, although of fair quality, was too crystalline, as well as somewhat porous. The water employed for condensation was thirty times in quan-

tity the water frozen; and both were taken, at temperatures of 70° to 80°, from the hot water well of the steam-engine. The cold current of the cisterns lowered progressively from freezing temperature down nearly to zero; and here it may be mentioned that, as an experiment of mere curiosity, or information, the temperature has at times been made to descend even to twenty-six degrees below zero. In the vacuum vessel the tension of vapor in the above experiment began with 5.7 inches of mercury, and ended with 2.7 inches. In the restorer the tension rarely exceeded two pounds above the atmosphere.

"By a trial, March 2, the product of ice was six hundred and sixty-one pounds in eleven hours ten minutes, with only four cisterns. By computing the aggregate of effect it was demonstrated that the machine could maintain a complement of at least one-third more cisterns than had been originally assigned to it.

"In different trials made during the summer, eight cisterns of the ten were put on. The machine will at any time freeze up in these cisterns fifty-six cakes of ice, each one foot square and six inches thick, and weighing together sixteen hundred and eighty pounds. With ten cisterns a ton could be frozen. This entire effect is produced by a pump of only eight inches and a half bore and eighteen inches stroke, working ninety double strokes per minute, together with small auxiliary pumps for water, ether, &c. In the greatest heats of July the vacuum vessel and the conducting pipes become coated with *snow*, and clear icicles hang down wherever water drops upon them. The machine has been operated, at different times, for some two years, and no corrosion of the metals has been observed, beyond the ordinary action of the atmosphere. In its *operations* there is no defect; but there are considerable defects of construction. In this last respect it has, as might be expected, the imperfections of a first machine—offering the experience by which great advantage will be realized in subsequent constructions.

"The ice produced by the above machine is equally sound with natural ice, and, doubtless, equally durable. Probably its specific gravity is even greater, on account of the complete expulsion of air during the congelation, and the consequent absence of air bubbles. It is either glassy clear or pearly white, according to the temperature and other circumstances of the freezing. Experiments, instituted for the purpose, show that these circumstances are capable of complete regulation."

ECONOMY OF PRODUCING ICE BY TWINING'S APPARATUS.

In regard to the economy of manufacture, the inventor presents the following estimates, which, having been made for 1857, may require some modification at the present time:

"The cost per ton of the ice produced is, for any particular locality, a question of mere arithmetic, when the data for calculation are well settled, viz., the price of fuel and of labor, and the scale of the manufac-

ture. For a scale of seventy-five to eighty-five tons each twenty-four hours, and wherever coal can be procured at ten dollars per ton, and ordinary labor at one dollar and twenty-five cents per day, the cost will be about *one dollar and a half* per ton, after the manufacture shall have become settled into its best condition. At first it may be prudent to count upon two dollars to two dollars and twenty-five cents. On a scale of say ten tons per day, the cost may, at first, range as high as three dollars and fifty cents. This inequality of cost is due mainly to the fact that the attendance upon a ten ton engine must be nearly the same as upon one of eight times the capacity. With respect to capital—meaning thereby the entire outlay for the establishment—it will be seen by the estimates given in detail below that a seventy-five ton establishment, in New Orleans, would require about one hundred and fifty thousand dollars. Probably a ten ton establishment, under the same circumstances, would require twenty-five thousand dollars or thirty thousand dollars.

Besides its low first cost the manufactured ice will afford several advantages of economy, compared with the imported article. *First.* Ice houses, except for a few tons capacity, will be dispensed with, as well as the labor of storage and of unpacking. *Second.* During distribution, or transportation, the cakes will lie packed like cut masonry. *Third.* The labor, time, and waste of dividing blocks and weighing will be done away with. *Fourth.* The surplus necessary, in irregular masses, to insure the delivery of full weight, will be saved. *Fifth*, and most important of all. The distributing carts will load at the manufactory; so that the article, delivered as just made, may unite the profits both of the present importation and, in a large measure, of the present distribution, still underselling the present market.

If the foregoing statements are well established, it is obviously a settled fact *that the warm climates of our country are soon to be supplied with artificial ice by means of this invention.* How much further this assertion might be justly extended is immaterial at present. Evidently where the demand is most urgent the supply should first be provided."

Professor Twining prepared, in full detail, estimates of the cost of erecting in a great city, say New Orleans, a manufacturing establishment, capable of producing eighty tons of ice per day. The amount of capital which would be required for the creation of such an establishment with its machinery complete, and including the cost of building and grounds, he concluded would not exceed one hundred and sixty thousand dollars. The daily expense of maintenance, including fuel, wages, repairs of machinery and building, oil, ether, and all contingencies, he computed at one hundred and twenty dollars. If to this we add interest at six per cent. on the investment, amounting to twenty-six dollars and thirty cents, the total cost of eighty tons would be one hundred and forty-six dollars and thirty cents, or one dollar and eighty-three cents per ton. It was a large allowance for waste and expense of distribution, therefore, when the inventor assumed, for purposes of comparison, the

total cost to the producer at five dollars or six dollars per ton, in the following statement of conclusions:

"The first cost of ice to the retailer in New Orleans at the present time—including waste and expense of distribution—is variously stated at ten dollars to sixteen dollars per ton. The same, under the new system, would be five dollars to six dollars. Ice, in that city and in most other southern cities, commands readily from twenty dollars to forty dollars. It is quite safe, therefore, to put the profit upon the manufactured article ten dollars per ton. Supposing then, at first, eighty per cent., or more, of the profits appropriated to reimburse the capital, principal and interest, and then, when the establishment *has cost the capitalist nothing*, the profits thenceforth to be divided equally between the capital interest and the patent interest, the foregoing data make it obvious that a very unusual margin of profits on the original investment is exhibited, even though that investment is already repaid."[1]

It cannot be too much regretted that an invention of such merit and importance, and of which the soundness and commercial value had been so fully demonstrated, both theoretically and experimentally, should, through the apathy or timidity of capitalists, have been permitted to lie neglected in the country in which it originated, till foreign enterprise had seized upon it, and developed it into a great industry.

[1] In the American Journal of Science and Arts for 1850 will be found two papers by Dr. John Gorrie on the heat developed by the compression of air. These papers are in substance a resumé of the results obtained by him in a series of experiments conducted on a large scale at the instance of some capitalists of New Orleans, who had in view, as he says, a commercial object—probably the manufacture of ice. These persons may have been the same by whom the enterprise spoken of in the text was set on foot. Dr. Gorrie writes under the impression, natural at that date, that the freezing effect of the dilatation will be equivalent to the heating effect of the compression. He endeavors, by the discussion of the results of his experiments, to ascertain the law which governs the relation between pressure and the ultimate temperature—a law which Poisson, however, had already established, and which it would be somewhat difficult to discover by methods entirely empirical. The experiments of Dr. Gorrie have a certain practical interest; but the progress which has been made within the last twenty years in the science of thermotics deprives them of value considered as contributions to theory.

CHAPTER XIII.

LIGHT-HOUSE ILLUMINATION.

DISPLAY OF OBJECTS CONNECTED WITH THE CONSTRUCTION AND OPERATION OF LIGHT-HOUSES—MODELS OF ENGLISH LIGHT-HOUSES—USE OF THE MAGNETO-ELECTRICAL MACHINE—WIGHAM'S GAS-LIGHT FOR LIGHT-HOUSES—THE GAS-LIGHT COMPARED PHOTOMETRICALLY WITH THE LIGHT FROM COLZA OIL LAMPS—THE BAILEY LIGHT-HOUSE—FLASHING LIGHT AT WICKLOW HEAD—REPORT TO THE BOARD OF TRADE UPON THE RELATIVE ADVANTAGES OF GAS AND OIL FOR LIGHT-HOUSE ILLUMINATION—LETTER TO ADMIRAL SHUBRICK—ELECTRIC LIGHT—LIGHT AS PRODUCED BY BATTERY—BY MAGNETO-ELECTRIC MACHINE—REGULATORS OF ELECTRIC LIGHT—THE BRITISH MAGNETO-ELECTRIC MACHINE IN THE EXPOSITION—THE FRENCH MACHINE—ECONOMY OF THE ELECTRIC LIGHT—THE ELECTRIC LIGHT AT LA HÈVE—FOG PENETRATING POWER OF THE ELECTRIC LIGHT COST OF MAINTENANCE AT LA HÈVE—LADD'S DYNAMO-ELECTRIC MACHINE—MAGNETO-ELECTRIC MACHINE OF DR. WERNER SIEMENS—WILDE'S MACHINE—EXPERIMENTS AND APPARATUS OF MR. C. W. SIEMENS AND OF PROFESSOR WHEATSTONE—ADVANTAGES OF LADD'S MACHINE.

It is not designed under this head to pass in review the various interesting objects connected with the construction and operation of light-houses which were brought together in the Exposition by the governments of England and France. The display made by these two great nations was exceedingly comprehensive in its extent and admirable in its character, well worthy indeed of the prominent position occupied by those nations as maritime powers. France exhibited not only every description of optical apparatus for illuminating light-houses, but also models and drawings of light-house towers, and even the real towers themselves. One of these, a beautiful iron structure, fifty-six metres high, (more than one hundred and eighty feet,) crowned with a revolving light of the first order, was constructed for the Roches Douvres, a reef off the north coast of Brittany, where it is to be placed after the close of the Exposition. Another was presented as an illustration of the form of the French harbor light-houses, and was only eight metres in height. Both the French and the British governments exhibited electric lights, the brilliancy of which, especially of the former, excited great admiration. The models of light-houses exhibited by England were particularly interesting. There were fifteen of these, presenting on a reduced scale not only the towers themselves, but also fac-similes of their sites and of the surrounding topography. There was also shown a model of the light-ship at the Goodwin Sands, one side of which had been left open to exhibit the arrangements of the interior.

The exhibition of light-house apparatus, however, complete and interesting as it certainly was, presented little that could be called new. The most important improvement made in the system of sea-coast lighting in

recent times has been the introduction of the magneto-electrical machine to supply illuminating power. This innovation was first made by the British light-house authorities in 1862, who, after some preliminary experiments made at the light-house of the South Foreland, established the electric light permanently at Dungeness; and it has been since adopted by the French government in the two important light-houses at La Hève.

The importance to the security of navigation, and therefore to the interests of commerce and the safety of property and life, of a system of coast lights, the most effective which can be obtained by combining all the resources of science and practical skill, gives to every proposition for the improvement of these lights a claim to a careful consideration. The point, therefore, to which, in connection with the exhibition of light-house appliances, the present reporter directed his attention with the deepest interest was electric illumination practically and economically considered in the light of the experience which has been thus far acquired in regard to it. The results of the inquiries instituted will be found below. In the mean time, it may be observed that, inasmuch as notwithstanding the superiority of the electric light, this light cannot be established except in localities where certain geographical and physical conditions conspire to favor its installation, the desirability of improving the illumination of light-houses by other modes is not by any means diminished. The following brief account of such an attempted improvement now gradually making its way in the British islands, will not, therefore, be without interest:

I.—WIGHAM'S GAS-LIGHT FOR LIGHT-HOUSES.

Upon the coast of Ireland, in the vicinity of Dublin harbor, there are one or two light-houses which, since 1865, have been illuminated by gas-lights instead of oil lamps. They furnish a light superior to that given by the largest four-wicked Fresnel oil-burner, by photometric measurement, as four to one. They are, at the same time, maintained at a cost less than had been previously required to light the same light-houses with oil, in the proportion of three to four. The plan having been in the first instance adopted experimentally, has since so fully established itself in the confidence of the light-house authorities of Great Britain and Ireland as to have been made permanent in the locality where it was first introduced; and measures have been taken to extend it to other points of the coast of both islands.

This important improvement had its origin in an effort made by the Ballast Board of Dublin to provide increased securities against the dangers to which shipping is exposed in approaching their harbor. In the following extract from the Irish Times for August 25, 1865, will be found some account of the measures taken by the board in the prosecution of this effort:

"The corporation for improving the port of Dublin, best known as the Ballast Board, is the authority having charge of the entire light-house

service of Ireland; and it is not saying too much that there is no corporate body in any country which, in the discharge of most important and responsible duties, gives greater satisfaction to the public, and more efficiently and promptly attends to the matters which come under its control, and upon which the safety of our maritime population so much depends, than the Dublin Ballast Board.

"The royal commissioners, in their report upon the condition and management of lights, buoys, and beacons, (1861,) bear testimony to the efficiency of this board and their care for the public welfare. One of the most recent proofs of this has been given in the establishment of a new light of very great brilliancy on the Hill of Howth, at the point known as the Bailey light-house. As the most easterly point of the bay of Dublin, and marking the entrance to our crowded river, it is of immense importance that the light in such a position should be of surpassing power, and, if possible, possess a capability of penetrating the fogs which at certain seasons of the year prevail upon our coast. Having this in view, the Ballast Board applied to Mr. John R. Wigham, gas engineer, of the firm of Edmundson & Co., of Capel street, a gentleman of great experience in such matters, to make certain experiments with the view of discovering a light of greater illuminating power than any hitherto used in the light-houses of Ireland, and the result has been the invention, by Mr. Wigham, of what may be termed an oxygenated gas-light of great intensity. The great peculiarity of Mr. Wigham's light is its whiteness. To this is due its power of penetrating fogs to a much greater extent than any other lights used for light-house purposes, excepting, indeed, the lime light and the electric light. The danger of explosion connected with the use of the former, and the expense and complicated machinery required for the production of the latter, render both of them unsuitable for universal application. But Mr. Wigham's system is exceedingly simple, and, requiring no skilled labor to direct its operations, is suitable for any position, no matter how remote or isolated. We have had an opportunity of making photometric observations respecting it, and find the light produced by Mr. Wigham's invention to be nearly three times greater than that afforded by the large four-wick oil lamps heretofore in use in the dioptric lens apparatus of the first order power of light-houses, while it would appear that the cost is considerably smaller in proportion.

"Having satisfied themselves by repeated experiments of the superiority of the new light, the gentlemen comprising the Ballast Board, with their chief adviser, Captain Roberts, R. N., one of the highest authorities upon such subjects in this country, determined to adopt it at the Howth Bailey light-house, and consequently our seafaring friends and those residing on the coast of Kingstown, Dalkey, &c., have had for some time back the opportunity of observing its brilliancy, which strikingly contrasts with the old light exhibited from that point. All the parts of the apparatus necessary for producing Mr. Wigham's new

patent light are manufactured in Dublin, and thus, through the instrumentality of the Ballast Board, a new source of manufacturing industry is likely to be opened up.

"The deputy master of the Trinity House Corporation of London, (the board having the control of English light-houses,) accompanied by several of the elder brethren, having heard of the new light, came across in their steamer (the Argus) specially to inspect it. They expressed themselves much pleased with its appearance, and the deputy master spent some time in testing its superiority by means of Mr. Wigham's photometric apparatus. It must, therefore, be gratifying to every one interested in the prosperity of this country and its advancement in manufactures, that this light of Dublin invention is likely to find its way into English and Scotch light-houses, as well as Irish, and that foreign countries also will avail themselves of a discovery eminently calculated to lessen the danger of the seas and promote the prosperity of maritime commerce."

The following additional notice of the new light is from the Dublin Daily Express of the 28th August, 1865:

"The great prevalence of fogs on large tracts of our ship-studded shores is, as is well known, the cause of much of that lamentable loss of life and property which takes place at sea. Heretofore fog-bells, placed on the dangerous parts of our coasts, have been in use, but only with partial success, to supplement the ordinary beacons—the light-houses. The light diffused by the latter, though amply sufficient in clear weather, will not penetrate a sea-fog to such a distance as will secure, or even materially assist in securing, the safety of the mariner when exposed to such a danger. Even landsmen require not to be told how a light which can be seen in clear weather from a great distance, becomes invisible a few yards off when surrounded by a fog. The lights at present in use in the light-houses on the English and Irish coasts are generally powerful enough to be visible in clear weather as far as any light can be seen, namely, until they disappear beneath the horizon; but in hazy or foggy weather they are almost useless. It is, therefore, obvious that the invention of a light which shall be intense enough to overcome, to a great extent, the resistance to its diffusion which foggy weather presents, would be one of great importance. Toward the discovery of such a light the Dublin Ballast Board have recently been directing their attention, and very considerable success has attended this movement on their part. After partially succeeding in their attempts to improve the ordinary oil light hitherto used in the light-houses under their control, and, indeed, in all light-houses, they, feeling satisfied that some still more powerful and equally available description of light might be procured, applied to Mr. John R. Wigham, of the firm of Messrs. Edmundson & Co., of this city, and requested him to use his knowledge and practical experience as a gas engineer in solving the important problem. That

gentleman, believing that light obtained from gas was more capable of improvement than that produced from oil, commenced operations by experiments having for their object the invention of gas of a better and purer quality than that in general use. He not only succeeded in producing gas of a quality much superior to any hitherto made, but he obtained that result by the simplest means—the gas being produced from oil by a safe and simple process. The light thus produced, and which is denominated oxygenated oil gas, is of intense brilliancy. On its being shown to us in Messrs. Edmundson's establishment it appeared to cast over the room, which had been previously darkened, a light of a similar, though, of course, not equally intense, whiteness and purity as is produced by electricity or the magnesium wire; and we could easily understand how powerful it must prove when transmitted by the carefully-adapted apparatus fitted up in all light-houses.

"As is well known, all gas, though giving out a pure white light as it emerges from the burner, yet becomes dark and smoky at the extremity of the flame. This defect Mr. Wigham has succeeded in obviating by a very simple yet ingenious method, so that the entire flame becomes equally white and pure. Another recommendation which it possesses is, that notwithstanding its superior power—giving about three times as much light as the old light-house oil-burner—it can be produced at even less cost, and it does not require the presence of skilled labor to superintend or manage it.

"On the 16th instant this new light was substituted for the old oil light formerly in use at Howth Bailey light-house, and with complete success, its great brilliancy being the subject of general remark on the part of all who have witnessed it. The Ballast Board sent a deputation of their number to test the comparative power of the new and old lights, and the result was most satisfactory. The deputy master and other members of the Trinity House Corporation, London, have since also inspected it, and expressed their unqualified approval of it; and we may expect shortly to hear that it has been adopted by them for the purpose of illuminating the English light-houses which are under their charge."

Interested by the statements which had reached him concerning this light during the summer of 1867, the present writer, at the close of the Exposition in November of the same year, visited Dublin for the purpose of becoming personally familiar with the facts in regard to it. He was received with great courtesy by the gentlemen of the Ballast Board, by whom every facility was allowed him for visiting the light-houses into which the new system had been introduced, and for examining all the details of the constructions, and testing the performance of the apparatus. Mr. John R. Wigham, their gas engineer, very politely placed himself at the writer's service, and personally accompanied him, first to the light-house on the Hill of Howth, where the new light had been in use about two years; and afterwards to Wicklow Head, about twenty miles from Dublin, at which all the constructions and preparations for introducing

it had just been completed. The Wicklow light is a flashing light, and it serves to bring out some points of the superiority of the new system of illumination more strikingly than the other, which is fixed.

Before visiting the light-houses an opportunity was offered the writer to compare, photometrically, the intensity of the gas-light with that of the flame of a first-class four-wicked Fresnel oil-lamp, burning the best kind of colza oil. The comparison was made in the photometric gallery of Messrs. J. Edmundson & Co., of Capel street, Dublin, the house of which Mr. Wigham is a partner. The gas-burner, which was a facsimile of those used in the light-houses, consisted of a cluster of thirty jets arranged in concentric circles, and giving a very powerful compound flame. The result more than sustained the statements contained in the extracts from the Dublin journals above given, as the photometer showed a superiority on the part of the gas-light as four to one. This was understood to be owing to the improvements which have been made upon the apparatus since its first introduction.

THE BAILEY LIGHT-HOUSE.

The Bailey light-house on the Hill of Howth was next visited, and an attentive examination was made of the arrangements for manufacturing and purifying the gas, as well as of the fixtures for exhibiting the light in the lantern. The stand for the lamp is not removed; but the lamp itself is promptly detachable, being united with the stand by a simple joint made secure against leakage and hydrostatic pressure by means of mercury. When the lamp is in place, the oil is supplied from a reservoir of suitable height within the lantern. The supply is cut off when the lamp is to be removed, by means of a stop-cock. On raising the lamp a certain amount of oil escapes from it, which is caught in a receiver attached to the stand, from which it may be drawn off and returned to the reservoir. When the gas-burner is introduced, it takes the exact place previously occupied by the lamp, being adapted to its own support by means of a mercury joint similar to that above mentioned in speaking of the lamp. As the support is necessarily a little eccentric in the lantern, the leading tube below the burner is so curved as to bring the cluster of gas-flames precisely into the required position. Above the burner is placed a large glass chimney, which serves to create a draught by which smoke is effectually prevented, and the flame is made intensely bright and clear.

An opportunity was afforded to the writer to see the change effected from gas to oil. The burner was removed and the lamp substituted in its place and lighted, all within about one minute.

The gas which was used in the earlier experiments was manufactured from oil, but the material now employed is cannel shale. This is distilled in retorts precisely like those of our ordinary city gas works. Two retorts were used at Howth Bailey, but in the construction of the new works three have been introduced as affording greater security against possible accidents.

FLASHING LIGHT AT WICKLOW HEAD.

A visit was made on a subsequent occasion to the flashing light at Wicklow Head, about twenty miles distant from the former by land. Here the great advantage of gas for intermittent flames was made very strikingly evident. By means of a simple clock-work movement and a mercurial valve, the gas is instantaneously cut off at the proper moment, and is afterward as instantaneously rekindled by means of small maintaining flames, such as are to some extent in use in this country for domestic lights. The mechanism previously used to display and conceal the oil light was greatly more elaborate, and was liable, on the least disturbance of adjustment, to work with a clatter, which, being re-enforced by the vibration of the entire column of air in the tower, was almost deafening.

RELATIVE COST OF GAS AND OIL.

At the time of the writer's visit to Wicklow Head, in 1867, the gas-light had only just been introduced. With the caution with which light-house authorities proverbially proceed, the results of the single experiment at Howth had been watched for nearly or quite two years before the introduction of the system elsewhere had been permitted. Early in 1867 a report on the subject was called for by the Board of Trade in London, which was furnished by E. F. Roberts, esq., inspector of lights, of Dublin, as follows:

"The experiments commenced in the year 1865 with gas made from oil, and subsequently with gas made from shale, the latter being more economical, and showing an equal amount of light.

"On comparing the gas with a four-wick lamp, the photometer showed the gas-light to be four times greater in intensity and quantity than the oil light of the four-wick burner, such as is used in a first class dioptric apparatus.

"Several comparisons were made by observing the effect of each from the Princess Alexandra steamer at night, in the following manner, viz:

"The four-wick oil lamp at Howth Bailey was lighted for half an hour to enable the flame to reach its proper height; it was then suddenly extinguished, and the gas was exhibited in the space of a few seconds, when the superiority of the gas was very manifest. These experiments were made on many occasions.

"Again, the steamer was taken to a position equidistant from Howth Bailey and Wicklow Head, the night being perfectly clear, both apparatus of the same order, and both, when burning oil, showing the same brilliancy; but, on substituting gas at the former station, its superiority was again very evident.

"On the 27th of December, 1866, an accident happened to the gas, owing to a defect in the coupling of the gas-pipe, when oil had to be used, which was done in about a minute. But such an accident is not likely to occur again.

"I would still recommend the gas to be continued at Howth Bailey, and also adopted at Wicklow Head for the intended intermittent light, but in no case would I propose it without having oil in readiness, as a stand-by in case of accident.

"Annexed is a statement of the annual cost of maintenance of gas-light for the year 1866, exclusive of the interest on the first cost for fitting up the gas apparatus, (which amounted to the sum of two hundred and forty pounds,) also a statement of the expenditure for maintaining the oil light at Wicklow Head during the same period, the lamps at this station being exactly similar to those at Howth Bailey.

"OIL.

"*Annual statement of the quantity of oil and other material expended in maintaining the oil light at Wicklow Head light-house station, with the cost of same, between the* 1*st January and* 31*st December*, 1866.

	£	*s.*	*d.*
780 gals. of oil at 4*s.* 9½*d.*	186	17	6
Lamp wicks	5	6	0
Cylinders	4	4	0
Carriage of oil, &c	4	8	0
Burners, and repairs of burners	3	10	0
Total	204	5	6

"PATENT GAS.

"*Annual statement of the quantity of fuel, materials, &c., expended in manufacturing gas at the Howth Bailey light-house station, with the cost of the same, between the* 1*st January and* 31*st December*, 1866.

	£	*s.*	*d.*
Coal, 38 tons, at 24*s.*	45	12	0
Shale, 14 tons, at 67*s.* 2*d.*	47	0	4
Lime, 96 hhds, at 1*s.* 4*d.*	6	8	0
Labor, 365 days, at 2*s.*	36	10	0
Cylinders, 35, at 1*s.*	1	15	0
Oil, (during accident to gas,) 5 gals. at 4*s.* 10*d.*	1	4	7
Wear and tear, fixing spare retort	6	0	0
Wear and tear, fixing new gas burner	2	0	0
Total	146	9	11

"Total number cubic feet of gas produced 120,439
"Total number cubic feet of gas consumed .... 118,137"

In consequence of this report the following correspondence took place between the Board of Trade and the inspector, which is introduced as covering the principal points of practical interest in this system of light-house illuminations:

THE SECRETARY OF THE BOARD OF TRADE TO CAPTAIN ROBERTS, R. N.

"BOARD OF TRADE, *Whitehall, March* 30, 1867.

"SIR: With reference to the report upon the shale gas-light at Howth Bailey light-house, forwarded in answer to a query, I am directed by the

Board of Trade to request that they may be furnished with the following additional information:

"1st. The cost of the entire apparatus, machinery, and buildings required for the system of gas illumination.

"2d. The space occupied by the apparatus, &c., *i. e.*, the size of the buildings for the apparatus, including stowage of coal, shale, lime, &c., over and above the space necessary for the common system, and whether such space could be obtained at a rock station, where the tower alone is available.

"3d. Whether additional labor is required, as it has been charged at Howth Bailey.

"4th. How is the crocus burner used, with reference to the common dioptric apparatus? Is it placed in the focus of the lenses, or is it independent of them?

"5th. When the accident happened to the gas, how long did it take to repair; and supposing it had occurred where no aid was at hand beyond the keepers, could the accident have been remedied?

"6th. Is the retort liable to sudden injury, and what would be the result?"

REPLY OF CAPTAIN ROBERTS.

BALLAST OFFICE, *Dublin, April* 24, 1867.

"SIR: With reference to the Board of Trade's letter of the 30th ultimo, requesting that they may be furnished with additional information respecting the system of gas illumination for light-houses,

"I beg to submit to the board the following answers, viz.:

"1st. The cost for the entire apparatus, machinery, and buildings, requisite for this system of illumination, depends to some extent on the position of the light-house to which it is to be adapted; but taking, for instance, Wicklow Head, the following is an approximation of what the cost is likely to be, viz.:

"A complete gas apparatus, with crocus burner and buildings, including coal-store, is estimated to cost as follows:

[Here follow specification and details of cost, omitted.]

"2d. The space required for a gas apparatus would be about sixty feet by twenty feet, including storage for coal. I am of opinion it would not be suitable to apply gas to any rock station, where such space outside the tower could not be had, as it would not do to make gas in the tower.

"3d. I consider one additional laborer is necessary for making the gas.

"4th. The crocus lamp is placed in the focus of a lens, and is removable and replaceable by the ordinary oil lamp in three or four minutes. No alteration of the lenses is required in the case of using gas.

"5th. The accident referred to in my report was simply a leakage. The light-keepers found it as they were going to light up, just before sunset, and although they could easily in a few minutes have repaired it with a

little white lead, yet they thought it better to light the oil lamp and repair the leakage by soldering, which they did; and at 9.30 p. m. they took away the oil lamp and lighted the gas, the change occupying one minute and a half.

"A similar leakage cannot occur again, as the brass cap which was in contact with the quicksilver of the coupling, and which had become corroded by the action of the quicksilver, has been replaced by iron, which will not be so acted on by the quicksilver.

"6th. The average duration of a retort is one year; they sometimes last much longer. They seldom crack suddenly, but this does sometimes happen. Such a crack can generally be easily staunched with a little tar and fine coal dust, and a retort so treated often lasts a long time. When a retort at any time, either from ordinary wear or sudden cracking, becomes too leaky for use, recourse is had to another, which can be used until it in its turn requires to be replaced. By the arrangement proposed for Wicklow Head, the three retort beds are to be so constructed that a new retort can be placed in any of them without stoppage to the gas manufacture, so that there will be little chance of failure in the light from breakage of retorts; and as they are almost the only perishable part of the apparatus, the continuance of the light is pretty certain, and in addition there is the 'stand-by' of the oil lamp."

As the result of these inquiries, an order was shortly after issued for the introduction of the new system of gas-lighting at Wicklow Head.

In addition to these evidences of the superiority of the new light, it may be stated that numerous written testimonials in its favor have been given by the most experienced navigators frequenting the port of Dublin, including the officers of the royal navy commanding the royal mail steamers entering that port. From all that he had thus seen and heard upon the subject, and in view of the magnitude of the improvement and of the simplicity and cheapness of the means by which it had been effected, the writer became strongly impressed with the desirability of introducing a system possessing so great advantages into some of the more important light-houses upon the American coast. Owing to the necessity of manufacturing the gas upon the spot where it is to be used, the system is not adapted to light-houses upon isolated rocks, or to minor lights remote from the sources of supply of the necessary material; but in such localities as Fire Island, Sandy Hook, and many other points in the approaches to our great seaport towns, its introduction would be unattended with difficulties of any kind, and it could not fail to promote in a high degree the security of navigation. Impressed with these views, the writer availed himself of the earliest opportunities which presented after his return to this country, in the winter of 1867, to bring the subject informally to the attention of members of the Light-house Board of the United States. At the expressed desire of some of these gentlemen, he went so far as to obtain exact estimates of the probable cost of constructing and maintaining the necessary works in connection with a light-house in a selected locality, from Messrs. J. Edmundson & Co., of

Dublin, the originators of the system, and from a competent gas engineer of New York. These estimates, accompanied by drawings, were forwarded to the chairman of the Light-house Board at Washington, with the following explanatory letter, dated Columbia College, New York, April 10, 1868, and addressed to Admiral W. B. Shubrick, chairman of the Light-house Board:

LETTER TO ADMIRAL SHUBRICK.

"I have the honor to forward to you, herewith, estimates of the cost of constructing and erecting gas works suitable for supplying a first-class light-house, proposed to be illuminated by Wigham's patent crocus gas-lamp, as actually employed at the Howth Bailey and Wicklow Head light-houses, in Ireland.

"There are two estimates entirely independent of each other; one by J. Edmundson & Co., Dublin, the house to which Mr. Wigham belongs, and the other by Mr. H. J. Davidson, a civil engineer of this city, who has had experience in the erection of gas works, and whose drawings are taken from works actually existing in this city. Mr. Davidson's estimates and drawings were furnished before I had received those of Edmundson & Co. Both reach substantially the same result. Each includes something which the other does not.

"Edmundson & Co. propose to deliver in New York all the apparatus necessary for the purpose proposed, upon the plan of the works at Wicklow Head, (the most recently constructed of the Irish works,) and to put in place all the pipes and fixtures necessary for illumination, including alteration of the present oil-lamp so that it may be used interchangeably with the gas-burner in case of need; but do not undertake the erection of buildings or the setting of retorts.

"This estimate amounts to one thousand and fifty-five pounds; or, with gold at one dollar and forty cents, say to seven thousand four hundred dollars.

"Mr. Davidson proposes to furnish everything in Edmundson & Co.'s offer, with a second purifier, a washer and a meter besides, which are not required at Wicklow; but he does not undertake the erection of the apparatus and fixtures, nor will he provide the burner.

"His estimate is six thousand dollars, with a gas-holder of one thousand cubic feet capacity. But as a larger gas-holder—say two thousand five hundred cubic feet—will be necessary, his total will amount to seven thousand five hundred dollars, or about the same as that of Edmundson & Co.

"From Mr. Davidson's estimate may be deducted the value of the parts not necessary, which will reduce the total below seven thousand dollars.

"Neither estimate includes the cost of buildings, nor the work of setting the retorts, or of constructing the tank of masonry required for the gas-holder. Mr. Davidson states to me that all these expenses may be

kept within four thousand dollars, or perhaps three thousand five hundred dollars, but that the retort house ought to have an iron roof, (this is not the case at Howth Bailey or Wicklow, but I think it ought to be,) and such a roof will cost one thousand dollars.

"Both propose to deliver the works in New York. Transportation could not cost to any point which the board would probably select for the experiment—for instance, Sandy Hook—a very large sum.

"I put down, therefore, as quite outside estimates of all the items involved in the original outlay:

Buildings	$4,000
Iron roof retort house	1,000
Works (in New York)	7,500
Transportation	500
Total	13,000

which is probably one or two thousand dollars in excess.

"As to the expense of maintenance, the crocus burner carries thirty bats-wing jets, each burning, it may be assumed, five cubic feet per hour, or the whole, one hundred and fifty cubic feet per hour, and one thousand eight hundred cubic feet on an average per day, through the year. The total consumption will therefore be six hundred and fifty-seven thousand cubic feet per annum, which will require seventy-three tons of coal to produce it.

73 tons of coal, at $9 per ton	$657
800 bushels of lime, at 10 cents	80
Total cost of production of gas per annum	737

"The actual cost at Howth Bailey for illuminating material during the year 1866 was £100 4*s.* 11*d.*; or, at the present price of gold, about seven hundred dollars.

"At Wicklow Head, during the same year, (the gas-lamp not having been yet introduced,) the cost of the oil consumed, as delivered at the light-house, was £191 5*s.* 6*d.*, or about one thousand three hundred and forty dollars. The lard-oil used in the American light-houses may, however, be cheaper.

"If gas is introduced into any of our light-houses, an additional attendant will be necessary; his services will, perhaps, cost five hundred dollars per year. We may put, then,

Cost of illuminating material	$737
Cost of additional labor	500
Total	1,237

showing a slight economical difference in favor of gas; the incidental expenses being about the same for both modes of lighting.

"As to the quality of the light, I can testify, from my personal observation, to the great superiority of the gas-light. During a stay of sev-

eral days at Monkstown, near Kingstown, Dublin harbor, last November, the Howth Bailey light was every night visible at a distance of six miles, and was greatly more brilliant than a first-class oil light with a catadioptric lantern of the same description situated at half the distance."

It will be noticed that, in these estimates, the values given are in excess, especially for the maintenance of the light, of what they are likely to prove to be. Coal delivered at Sandy Hook will probably cost more nearly six than nine dollars per ton. The additional labor required will probably be obtainable for two or three hundred dollars per annum, instead of five hundred. If the same description of coal is used as at Howth Bailey, a much less weight will be necessary than is here assumed, though at a price in like proportion perhaps advanced; but the gas will be richer and the volume consumed very greatly less.

Supposing, however, that there should be nothing whatever gained; or even supposing that the expense of the gas-light should be sensibly greater than that of the lamp-light at present used, the advantage secured by the change would be out of all proportion to the increased cost, since the intensity of the light would be increased four-fold, and the range of its visibility in moments of danger would be correspondingly extended. If a single ship of the multitudes which founder in the approaches to the harbor of New York should be saved from destruction in consequence of the adoption of this superior light, the value of this one vessel with its cargo alone would be sufficient to pay the increased expense consequent upon the adoption of the improvement for an entire century. The project is still before the Light-house Board. It is to be hoped that that body may deem it at length to be worthy of a trial.

II.—ELECTRIC LIGHT.

The intense light produced by the current of a powerful galvanic battery passing between two carbon points, early suggested the possibility of employing electricity for purposes of illumination. This could only at the time seem a remote possibility, for the want of permanence and uniformity of force in the currents generated by the only batteries then known, restricted within narrow limits the duration of the phenomenon and the steadiness of its brilliancy. When, about thirty years ago, sustaining batteries had been created by Daniell, Grove, and others, the problem became more feasible, and excited a new interest. In the mean time, however, two great discoveries had been made. In 1819, the influence of the electric current upon the magnetic needle, first detected by Oersted, laid the foundation of that important branch of electrical science to which, among other great benefits, the world owes the electric telegraph, and which is known as electro-magnetism; and in 1830, the production of a spark from a circuit of copper wire, suddenly interrupted in presence of a magnet, a result reached by Faraday in the prosecution of his ingenious experimental researches upon electricity, was the elementary fact out of which has since grown the converse branch called

magneto-electricity. The discovery of Faraday was speedily prolific of important consequences. It was found that magneto-electric machines might be constructed which should furnish, not merely sparks, but powerful currents. For many of the purposes for which electricity had been employed it was found entirely practicable to substitute instead of the battery—the maintenance of which, when great power is required, is attended with inconvenience and other disagreeable concomitants—an apparatus of a much higher degree of simplicity, and demanding only, in order to produce the same effect, the expenditure of a certain amount of mechanical force. Magneto-electricity has accordingly in recent years, to a certain extent, superseded the battery current for many practical purposes, and especially for the uses of the galvanoplastic arts.

The magneto-electrical machine is peculiarly adapted to the purpose of illumination. As its parts are all unchangeable, or undergo only the changes incident to wear and tear, the force of the current which it produces will depend only on the amount of mechanical force which is consumed in driving it. And as this can be maintained sensibly constant, the same constancy will characterize the current. Still, however, the problem of producing a steady light by means of electricity is not altogether easy of solution. Though the current may be one which in a perfectly uniform conductor would be constant, it is a condition essential to the production of the light that the circuit should be broken. The light is produced between two carbon points introduced into the circuit at the point of rupture. These are usually made of the very hard incrustations which form spontaneously in the retorts of gas manufactories; and the substance is on that account called gas-carbon. The electric generator—magneto-electric machine or battery, as the case may be—being in action, these carbon points are brought momentarily into contact, and then separated from each other. While contact continues, no light appears. In the instant of separation the light bursts into brilliancy. The distance of separation which is practicable will depend on the intensity of the current. If this distance is made too great, the current will cease to pass. A certain degree of intensity is necessary on the other hand, in order that there may be any separation at all without a cessation of the current; or in other words, that the production of light may be possible. With a given perfectly sustained force of current, and a given pair of carbon points, it would seem, then, that after having found the degree of separation of the points which produces the most brilliant illuminating effect, we should only have to fix them there to make this effect permanent. And this would be true but for the fact that the points gradually waste and thus increase the distance separating them. If, therefore, they should be fixed in their places, as just suggested, the current would finally fail to pass, and the light would become extinct.

When the experiment is performed in the lecture-room for purposes of demonstration, the experimenter can compensate the gradual waste of the carbons by advancing one or the other of them with the hand. This

is even practicable, though not quite convenient when the light is employed for optical purposes, as in the magic-lantern and miscroscope, since its variations are not generally very rapid. But, for a permanent light, unless there can be provided an automatic and certain compensation for this waste of the points, the electric light, notwithstanding its beauty and brilliancy, cannot be made available.

Happily the properties of the electric current itself suggest the means of providing such a compensation. When this current passes through a wire in the form of a helix enveloping a rod of soft iron, it converts the rod into a magnet. It is not necessary that the helix should touch the rod; the effect follows if it only surrounds it. Moreover, in these circumstances, if an attempt is made to withdraw the rod from the helix, there will be felt very distinctly a resistance arising from the attraction of the current in the helix for the rod, an attraction which is only satisfied when the middle point of the length of the rod coincides with that of the helix. The force of this attraction varies with the strength of the current. An effort which would suffice only to remove the rod a slight distance from the position of equilibrium when the battery current is high, would produce a much larger displacement when this current is greatly reduced.

In this fact we have the principle upon which the automatic regulators of electric light, of which quite a number have been produced by different inventors, must necessarily all be founded. Suppose one of the carbon points to be fixed and the other to be connected with a bar of iron which partially enters a coil of wire; through this coil the same current may be made to pass which produces the light. The attraction of the coil will draw backward the bar, and with it the carbon. In order to prevent too large a movement, this attraction may be counteracted by a spring of such force that the carbon remains stationary at the point most favorable at the moment to the production of the light. As the carbon points waste, the distance between them will increase and the current will be enfeebled. The elastic force of the spring will then prevail over the attraction of the coil, and the points will approach each other. And as the wasting of the carbons and the approaching of the points are both gradual, the light will be subject to no abrupt change of intensity. It is obvious, however, that a contrivance constructed in this simple form could be serviceable only within certain rather narrow limits; for, in order that the spring may prevail it is necessary that the magnetic force should grow gradually less; that is to say, that the actual distance between the points should after all increase, and the light correspondingly diminish. An automatic regulator of electrical light requires, therefore, for its satisfactory performance, the introduction of other mechanical expedients, which it is not necessary here to describe.

It is a condition of the production of the electric light that it cannot be produced in larger or smaller quantity at pleasure. It cannot be produced *at all* except by a current which has power to pass through a sen-

sible interval separating the two poles of the battery, or, as they are called, the electrodes. And a current of this degree of power, when it becomes luminous, becomes intensely so. The electric light is therefore unsuitable for the ordinary uses of domestic life, but for purposes of public illumination, and especially for sea-coast lights, it seems to be admirably adapted. It has been introduced by the governments of both Great Britain and France in one or two of their first-class light-houses; by the former at Dungeness, and by the latter at La Hève, near Havre. The British light was established in 1862; the first French light, a year or two later. In both cases the electricity is generated by powerful magneto-electric machines driven by steam-engines. It was stated in the earlier reports that a force of one and a quarter horse-power was required to drive the British machine, and one and a half horse-power to drive the French. In practice, the French have employed a force greater than this, equal to two and a half horse-power for each machine.

Both these governments have exhibited their lights in the Exposition, and the French machine has been visible to the public for some hours daily. The British has been less freely open to inspection, and on the only occasion on which access to it has been obtained, it was enveloped in a covering of canvas, which made a detailed examination impossible. A description of this machine, however, or at least of one quite similar exposed in London, in 1862, furnishes all the essential particulars in regard to its construction.[1] The machine embraces eighty-eight bobbins, or coils of copper-wire, wound round as many hollow cores of soft iron, each containing ninety feet of wire No. 9. The wire is wound in double, the whole being equivalent to one wire of forty-five feet in length and two-tenths of an inch in diameter. The iron cores are three and a half inches long, one and a half inch in diameter externally, and one inch internally. They are arranged at equal distances from each other in the circumference of a large wheel five feet in diameter, their axes being parallel

[1] The information which, at the time of writing this article, (September, 1867,) was wanting, has been since furnished in a published report of Captain M. C. Close, a member of the Trinity House Light-house Board, and one of the British commissioners to the Exposition. It appears that the electro-magnetic machine exhibited in Paris by the British government was constructed upon a model somewhat differing from that of the Dungeness machine described above. Since the differences, however, are not differences of principle or even of form, but only of the number of parts and of their arrangement, it has not been thought worth while to disturb the statements of the text but to note the necessary corrections in the present form.

In the machine which was exhibited at Paris the total number of magnetic bobbins is ninety-six, and these are arranged in six rings or wheels, and not in two as at Dungeness. There are, therefore, seven rings of permanent horseshoe magnets, instead of three. The bobbins of the successive rings are set, as described above, in such a manner that one-half the number shall be undergoing change of polarity, while the other half are in the middle of the spaces between the poles of the permanent magnets, and commutators of course have to be used. It is stated by Captain Close that experiments with this machine show that the number of changes of polarity per minute which gives the most intense illumination is six thousand four hundred.

to the axis of the wheel; and in two parallel rings, forty-four coils in each ring. The axes of one set or ring of coils are placed so as to correspond to the middle of the distance between those of the other ring. Sixty-six very powerful steel horseshoe magnets are firmly fixed in three rings parallel to each other, twenty-two in each ring, their poles all in the planes of their several rings, and distant from each other by a space equal to that which separates the centres of the bobbins. The magnets of the several rings are similarly situated upon the circumference, their poles being alternate; but the poles of those in the extreme rings face contrary poles in the central ring. Each magnet in the two external rings is composed of four separate plates, or simple magnets, combined, and each of those of the central ring of six simple magnets. The weight of each simple magnet is six pounds.

As the wheel turns, the cores with their bobbins pass between the successive poles of the fixed magnets; and owing to the equality of the spaces between the poles and the cores, all the bobbins of one ring pass these poles simultaneously; but owing to the dissimilarity of position of the two series of bobbins in their respective rings, it happens that while those of one set are passing the poles, those of the other are half-way between the poles. While the motion continues, alternate currents of opposite character are generated in each series of bobbins. The change of polarity and of corresponding electric flow occurs in the moment of the polar passage. Thus when the current in one set of bobbins is in the middle of its flow, that in the other undergoes a sudden reversal. By the arrangements known to electricians under the name of commutators, all the successively opposite currents are turned into the same direction in the circuit which conveys the electricity to the electric lamp. In this way the fluctuations which occur in the intensity of the current generated by one of the sets of bobbins are made to compensate those of the other, and the resultant intensity is nearly or quite constant.

As the twenty-two magnets of each ring present forty-four poles, there are forty-four changes of direction in each set of bobbins at every revolution, or eighty-eight changes in both. The velocity of revolution is at the rate of one hundred and ten turns per minute. The total number of changes of polarity in the same time is therefore nearly ten thousand. The intensity of the light produced depends on the rapidity of revolution. When the movement is slow the current is feeble, as when the machine is at rest there is no current at all. But though the intensity increases with the velocity, a limit is reached beyond which a further acceleration will tend to diminish rather than to increase it further, because the magnetization of the soft iron cores is not instantaneous, but requires a certain time, and too great a velocity of revolution induces a reversal of the current before the cores are completely magnetized. The most advantageous velocity can only be ascertained experimentally.

The French machine in some respects differs from the English. There are four rings of bobbins, instead of two, but only sixteen in each ring

or sixty-four in all. They revolve between five sets of steel magnets, eight in each set. All the bobbins are similarly situated in the circumferences of their respective rings, so that they all pass the poles of the magnets simultaneously. The diameter of the wheel, measured from centre to centre of the opposite bobbins, is one metre. The cores of the bobbins are hollow iron cylinders, one decimetre (nearly four inches) in length, and five centimetres, or about two inches, in external diameter. Their internal diameter is three and a half centimetres. Eight wires, one millimetre in diameter and sixteen metres long, are wound round each bobbin, and are united at their corresponding ends, being equal to a single wire of fifty-three feet long and eleven-hundredths of an inch in diameter. The magnets of the outside rings are composed of three simple magnets, weighing each four kilograms, or nearly nine pounds. Those of the intermediate rings have twice as many of the same size. The number of revolutions of the wheel is sometimes carried as high as four hundred per minute, giving over six thousand alternate currents in the same time. No commutator is used. It is an interesting fact that the production of light by a magneto-electrical machine is independent of the direction of the current, and unaffected by the changes in its direction, no matter how rapidly they may follow each other. The light is undoubtedly produced in successive flashes, but the minuteness of the interval between them prevents their being distinguished, so that the light is sensibly constant. When these machines are employed, however, for the purpose of producing chemical decompositions, it is obvious that the alternation of the current would neutralize the effect, unless a commutator were introduced.

In the English machine the commutator could not be dispensed with, for though, in its absence, the two currents would conspire in direction during a part of the interval between the pole changes, they would counteract each other during the remainder. It may even be questioned whether, to a certain extent, they do not produce this effect, notwithstanding the presence of the commutator. If, in the general circuit in which they are united, there were absolutely no resistance, each would indeed contribute its full force to the current. But if, in this circuit, the resistance were to become infinite, or, in other words, if the general circuit were entirely broken and the electrodes insulated, each of the two currents would be turned back upon the coils of the other, and the feebler would be reversed. In the case of their equality they would balance each other and there would be no flow. The resistance presented by rupture between the carbon points is not infinite, but it is considerable, and it must, therefore, produce some effort on the part of each current to return through the wires of the other. The French arrangement seems consequently to be more judicious than the English. It is attended with the additional advantage that the waste of the two carbon points is equal; a circumstance contributing to simplicity in the construction of the regulators.

In regard to the intensity of the light produced by these machines, as compared with that derived from other sources, Mr. Becquerel, in an article on the electrical apparatus exhibited in the Exposition of 1862, gives some interesting statements derived from the results of experiments made at Paris with a magneto-electric machine similar in construction to that above described, but having six sets of bobbins instead of four, or ninety-six in all. The permanent magnets were similar, and each was capable of lifting three times its own weight. The machine was driven by an engine of two horse-power, and the light produced, determined by suitable photometric measurements, was divided by two, in order to reduce it to the amount corresponding to a single horse-power. This amount was found, when the electrodes employed were of selected gas carbon, to be equal to a mean value of seven hundred stearine candles. Its greatest brilliancy was from one thousand to one thousand one hundred, and its least from four hundred and eighty to five hundred and twenty. With carbon of greater purity, specially prepared for the purpose, the mean light was from eight hundred to eight hundred and eighty, and the maximum nearly one thousand three hundred.

Mr. Becquerel proceeds to compare the light thus obtained, in point of economy, with that produced in equal quantity by the galvanic battery, by coal gas, by coal oil, by oil of colza, by tallow, stearine, and wax. In these estimates he assumes the price of gas to be thirty-hundredths of a franc per cubic metre, or seventeen cents the one hundred cubic feet; oil of colza, one dollar and twenty-eight cents per gallon; tallow, in the form of candles, sixteen cents; stearine, thirty-six cents; and wax fifty-two cents per pound. The cost of the electric light he assumes to be only that of the combustible required to run the engine. From these data he deduces the following values:

A light equal to that of seven hundred stearine candles will cost per hour—

1. Produced by the machine	2 to 4 cents.
2. Produced by the galvanic battery	38 to 94 cents.
3. Produced by coal gas	62 cents.
4. Produced by kerosene	73 cents.
5. Produced by pure oil of colza	\$1 14.
6. Produced by tallow candles	\$2 37.
7. Produced by stearine	\$5.
8. Produced by wax	\$6 10.

In point of cheapness, therefore, there would seem to be no comparison between the electric light and that produced by even the least costly of the materials ordinarily employed for purposes of illumination. Actual experiment, however, in the use of these machines in French light-houses, has shown that these figures require important modification. A report made in 1866, to the minister of public works, by Mr. Reynaud, inspector general of roads, bridges, light-houses, and buoys, upon the electric light established at La Hève in 1864, furnishes some valuable

information in regard to this matter. The lights at La Hève are of the first class and two in number, situated about one hundred yards apart. The lanterns are at one hundred and twenty-one metres (nearly four hundred feet) above the level of the highest tides. One of these lights only was replaced by electricity in 1864, the other continuing to be maintained, as before, by means of an oil lamp. The presence of the two descriptions of light, side by side, furnished thus the most advantageous opportunities to compare them not only as to the cost of maintenance, but also in regard to their regularity, the range of their visibility and their power of penetrating fogs. In regard to this latter property it is an important fact that the fog-penetrating power of a light is not necessarily proportioned to its brilliancy, whether as apparent to the eye or as photometrically determined. Fogs and smokes absorb powerfully the more refrangible rays of the spectrum, while allowing the red and yellow—that is to say, the most highly luminous—rays to pass with comparative facility. It is this which tints the clouds of the morning and evening horizon so forcibly with orange and rosy hues, since the horizontal rays of the sun then traverse, for a great distance, the lower strata of the atmosphere, which are more or less charged with mists. The light which is produced at excessively high temperatures is dazzling in its brilliancy, and possesses the whiteness of the solar light. This is due to the presence in it, in their full proportion, of the most refrangible and most easily absorbable rays. The electric light is of this character. In the light produced by the combustion of oils, on the other hand, these easily absorbable rays are but feebly represented, while the red and yellow are produced in abundance. Accordingly, in a time of fog, an electric light may show but a moderate superiority over a light produced by an oil lamp which, by photometric measurement, it at the same time exceeds in the proportion of eight or ten to one. In clear weather, on the other hand, it will have a much greater range of visibility.

The electric light established in 1864 at La Hève was provided with two magneto-electric machines like that above described, having each four disks of sixteen bobbins, and having each its independent driving engine. There were also provided two systems of Fresnel lenses, one above the other, having each two regulators for the carbon electrodes. This duplication of all the parts of the apparatus was especially intended as a guarantee against any interruption of the light by unforseen accident; inasmuch as in case one regulator failed, another could be substituted, and in case one machine ceased to perform, the other could be put immediately in motion. But an incidental and great advantage resulted also from this provision, which consisted in the power to double the intensity of the light whenever the atmosphere was unusually thick.

The power of the beam thrown by the magneto-electric machines originally established at La Hève, as concentrated by the catadioptric system of Fresnel, was found to be equivalent to that of three thousand

five hundred Carcel burners. The light which it replaced, and that of the companion light which for a time remained, had only the force of six hundred and thirty Carcel burners. After the new light had been put into operation, the point of principal interest first attended to was to ascertain, by comparative observations, the mean relative visibility or range of visibility of the two lights. Observations were accordingly made three times every night by the keepers of the three lights at Honfleur, distant fifteen kilometres, or eight and one-tenth miles; at Fatouville, distant twenty-one and a half kilometres, or eleven and six-tenths miles; and at Ver, distant forty-six and five-tenths kilometres, or twenty-five and one-tenth miles.

The following table presents the results:

Place of observation.	Distance.		Light observed.	No. of times seen in 100 observations.	Proportional value of the electric light.
	In kilometres.	In miles.			
Honfleur	15	8.1	Oil	88	1.04
			Electricity	92	
Fatouville	21.5	11.6	Oil	77	1.02
			Electricity	79	
Ver	46.5	25.1	Oil	33	1.24
			Electricity	41	

This table does not furnish a very fair test of the relative value of the lights. During the greater number of the nights of observation when both lights were seen, a much feebler light than either would probably have been equally visible, especially from the nearer points. During many of those in which neither was seen, it is probable that a much more powerful one than either would have been unobserved also. The table shows, nevertheless, that while the electric light is superior to the other, it is not so much superior as might have been anticipated. It shows, further, that its superiority is apparently more marked as the distance is greater; a fact, however, which is associated with the important additional fact that both lights are less frequently seen at great distances, or, in other words, are seen at such distances more frequently in clear weather, when the rays of high refrangibility are least absorbed. In foggy weather, on the other hand, though the electric light was seen twice or more in the hundred times oftener than the oil light, yet during those same times both the machines were in operation, and the power of the electric light was carried up from three thousand five hundred to seven thousand carcel-burner force, while the oil light remained constant at six hundred and thirty. An advantage, nevertheless, which the electric light very distinctly possessed over the other, was in its creating a kind of glow in the fog, by which mariners were enabled to recognize the position of the cape even when both lights were invisible.

An irregularity appears in the table, by which the superiority of the electric light would seem to be more marked at Honfleur, the nearer station, than at Fatouville, more distant. This is explained by the statement that the light of the oil lamp is somewhat obscured in the direction of Honfleur by the framework of the lantern.

An evidence perhaps more conclusive of the relative value of the lights than that which the table affords, is found in the testimony of navigators, who with one voice affirm that they always see the electric light before the other.

Experiments have been made with the view of ascertaining with some approach to accuracy the relative fog-penetrating power of the two descriptions of light produced by electricity and by ordinary combustion, when the photometric intensities are equal; and also the excess of intensity which must be given to the former light, in order that its power in this respect may be equal to that of a lamp fed by oil. In these experiments it was attempted to imitate as nearly as possible the absorbent effect of fogs, by interposing glasses of different colors, red, orange, yellow, &c., before each of the lights successively. The conclusion which these experiments seem to justify is, that whenever an electric light exceeds in intensity a light produced by a lamp two and a half times, it will penetrate at least as well as the latter the fogs most unfavorable to the transmission of the rays. And, as a fact, in whatever state of the weather, the electric light at La Hève has always had the largest range of visibility.

It is not to be set down as an objection to the use of the electric light that it requires to have this excess of intensity over the lights actually in general use, in order to be equally serviceable; because one of the conditions of the production of this light is that it shall be intense. And there is no difficulty in securing not only the required increase of intensity, but even a much greater one, with a much less actual expense. Thus, at La Hève, the ordinary intensity of the electric light is nearly six times as great as that of the oil light, and when both machines are in operation it is about eleven times as great.

The apparatus required for the production of the electric light is very much more complicated than that which is necessary to maintain that of the compound lamp in common use in light-houses. The possibilities of derangement are correspondingly multiplied. Accident may happen to the steam-engine, the magneto-electric machine may fail in some of its parts, or the regulator of the carbons—a delicate and somewhat complicated piece of mechanism—may cease to perform its functions regularly. It is on this account that the French government, in introducing the system into the light-house at La Hève, were careful to double every part of the machinery and apparatus, even to the costly optical combinations. An experience of fifteen months, however, demonstrated that the liability to interruption by accident was not great. During this period the number of accidents was ten. Five of these occurred with the engine, and

caused the extinction of the light for periods varying from three to fifteen minutes. They were traced to the inattention of one of the machinists; and in an interval of eight months after his discharge, there occurred but one more, which interrupted the movement only three minutes. Two accidents occurred to the magneto-electrical machines. In the first, in consequence of the fracture of a plate, there was a stoppage of ten minutes; in the second, owing to the derangement of a bobbin, there was, for a minute or two, a fluctuation of the light. These accidents suggested effectual measures for preventing the recurrence of similar misfortunes. The other accidents were owing to derangements of the regulators, and did not produce extinction.

The result of this experiment was so satisfactory to the French government, both as to the practicability of employing the new mode of illumination and as to its superior value, that it was resolved to extend the system to the second of the light-houses at La Hève. An order to this effect was issued by the minister in May, 1865, and the new apparatus was brought first into use on the second of November of the same year.

The apparatus for the service of both these light-houses is now installed in the same building, half-way between the two towers. It embraces four magneto-electrical machines, each having six disks instead of four, with sixteen bobbins in a disk. Two engines of five horse-power each are employed to run these. Ordinarily one engine only is in operation, driving a single machine for each tower. In heavy weather both engines are active, and each tower receives the combined currents of two machines. Both the light-houses have double catadioptric systems, one superposed above the other as in the arrangement originally introduced. The illuminating power of each of the new machines, as optically condensed, is equal to that of five thousand carcel lamps. By the combination of two at once, in time of fog, this great intensity can be doubled. Experience has shown that such a duplication will be necessary about four hundred hours in the year. No interruption has occurred since the installation of the new machines.

In regard to the question of economy several considerations have to be taken into the account, which were overlooked by Mr. Becquerel. In the first place, the prime cost of building will be considerably increased. A suitable apartment will be necessary for the engine, and a separate one for the magneto-electric machines. Then the *personnel* of the service will require an increase of at least two men. Moreover, the necessary supply of water for the engine will in many, and probably in most cases, present a problem of which any solution must be expensive. Headlands are chosen by preference for light-houses, where there are no natural springs, and where, on account of the height, it is difficult economically to raise water by pumps. The alternative presents itself to construct cisterns for the collection of rain-water. The cost of these will vary in different localities. At La Hève they have been constructed of sufficient

capacity to contain one hundred and seventy-five cubic metres, (nearly fifty thousand gallons,) at an expense of forty-six thousand francs—nine thousand dollars.

In regard to the maintenance of the light itself, in addition to the cost of fuel, which has amounted to nearly one thousand dollars per annum, there are to be considered the items of carbon electrodes, amounting to three hundred and fifty dollars; oil, hemp, cotton, &c., one hundred and eighty dollars; and repairs and maintenance of the engine and machines, four hundred and fifty dollars, overlooked by Mr. Becquerel, and in all forming a sum nearly or quite equal to the expense of fuel; besides the wages of two additional employés. The entire annual expense of the two lights, since both were furnished with the electric apparatus, has been seventeen thousand francs, or three thousand four hundred dollars, while it amounted to only fifteen thousand one hundred and sixty francs, or three thousand dollars, while they were lighted with oil. Taking into account, however, the superior intensity of the electric light, the expense per unit of light is as seven to one in favor of the electric light. The relative economy would be somewhat less, but still very nearly in the same proportion, if but a single light were to be provided for at the same station.

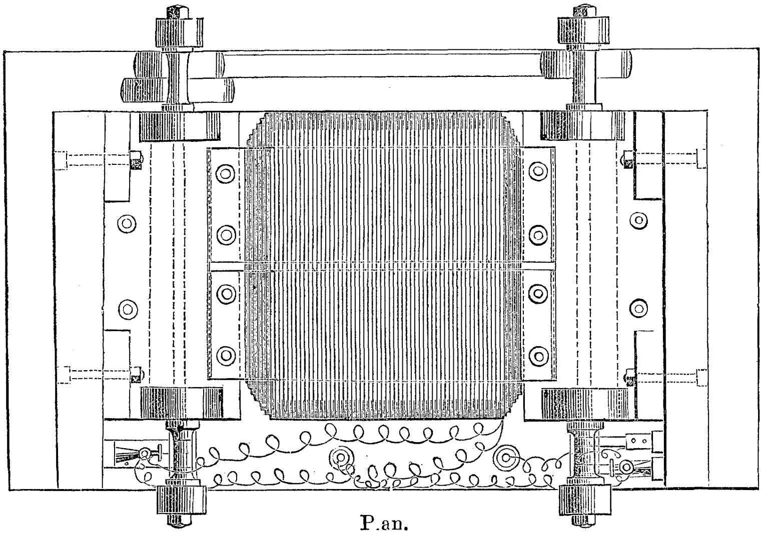
In regard to the practicability of extending the system of electric illumination to coast lights generally, the French inspector general is of opinion that, in the actual state of things, it can hardly be accomplished. The system is not economically applicable to minor lights, which are the class most numerous, while the magnitude of the constructions which it requires, and the quantity of coal which it consumes, are obstacles to its introduction in isolated positions, where it is important to reduce as much as possible both the size of the structures and the quantity of transportation.

Recent discoveries in electrical science give rise to the anticipation that the bulk and cost of magneto-electric machines may in future be materially reduced, and that possibly there may be also some reduction in the driving force necessary to produce a given intensity of light. One of the most remarkable of the objects presented in the present Exposition is the machine exposed by Mr. Ladd, of London, under the name of a dynamo-electric engine. This machine, of which a representation is herewith given, Fig. 87 consists essentially of a pair of soft iron plates of about twelve inches by twenty-four, and half an inch thick, wrapped with insulated wire about one-tenth of an inch in diameter to the depth of four layers. These plates are placed horizontally, one over the other, and have at each of their extremities a revolving armature. These armatures are of the form originally proposed by Mr. Werner Siemens, of Berlin, in 1857, being cylinders of soft iron deeply grooved in the direction of their length, and wound in the groove with insulated copper wire.

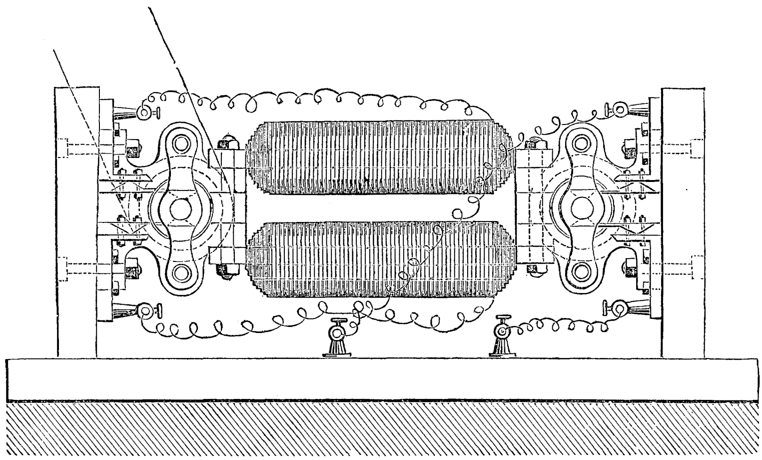
The armatures revolve in hollow cylinders of equal length, and only sufficiently larger to permit them to turn freely. These hollow cylinders

are formed of two thick bars of soft iron separated by an equally thick plate of brass all firmly united and then bored longitudinally. These hollow cylinders are interposed between the extremities of the broad plates

Fig. 87.



Plan.



Ladd's Dynamo-electric Machine—elevation.

wound with wire as above described, serving thus to keep them asunder, and the whole are firmly bolted together. The wires of one of the armatures are connected with a commutator, designed to give a common direction to the currents of electricity which may be generated in them; and the extremities of the wire which wraps the plates are connected with tangents resting upon this commutator. Supposing then the plates to be magnets, the combination described forms a magneto-electric machine, and in the rotation of the armature, electric currents will be

excited in its enveloping wire. The peculiarity of the arrangement is, that the currents thus developed will pass by the commutator into the wire which wraps the plates, and if the rotation be in the proper direction, will tend to reinforce their magnetism. If, however, the plates are not originally magnetic, at least in some degree, the rotation will produce no electrical effect. But supposing them to be originally unmagnetic, it will suffice to touch the extremity of one or both of them with a steel magnet to impart to them at least a trace of magnetism, and then, if the armature be rapidly revolved, a current will be generated which though at first feeble will quickly become very intense. For the magnetism of the plates is exalted by the circulation of the current in their enveloping wire, and this heightened magnetism in turn excites the current to increased intensity. The succession of mutual reactions here described, goes on until the rapidity of rotation is too great to allow the armature to be fully magnetized in each of its successively opposite polar conditions.

The other armature has been thus far supposed to be at rest; but if now the extremities of the enveloping wire of that armature be connected with the conductors of an electric lamp, and if this armature be also put into rapid rotation, there will be produced a light of most intense brilliancy. Or if, instead of the lamp, we employ a platinum wire to complete the circuit, this wire will be instantly ignited to incandescence, though of several feet in length and a twentieth of an inch in diameter. The power of this small machine is stated by the Abbé Moigno in his journal, *Les Mondes*, (May 22, of this year,) as equivalent to that of twenty-five to thirty elements of Bunsen.

This invention of Mr. Ladd is so recent that the machine exhibited in the Exposition is almost the first of its kind which has been constructed. The form and proportions most favorable to the effect remain, therefore, yet to be studied. But the surprising energy of the currents developed by an apparatus of the very moderate dimensions of that exhibited, justify the anticipation that the provision of electric light for light-houses will exact, hereafter, much simpler mechanical arrangements than it has done heretofore. Steel magnets, in great numbers and of great power, will no longer be required at all. If, in describing the mode of exciting Mr. Ladd's apparatus to activity, we have supposed for a moment the intervention of a steel magnet, this was for the sake of simplicity of explanation. No such expedient is necessary. Place the instrument with its polar extremities north and south, and the induction of the earth's magnetism suffices. In the beginning it was supposed that it would be at least necessary to introduce into the circuit a feeble galvanic battery, but experiment has proved otherwise. Indeed, after the machine has once been operated, it will not even be necessary to call in the aid of terrestrial induction. Traces of magnetism will hang round even soft iron for a long period after it has been once magnetically excited, and these traces will suffice to start the series of reactions

by which the power of the machine is developed, whenever the armature is put into motion.

The idea of turning back upon an electro-magnet, for the sake of augmenting its power, the current generated by itself in the envelope of an armature revolving before its poles, is not original with Mr. Ladd. It is the second armature, introduced for the purpose of generating a current capable of being directly utilized, which constitutes his invention. The history of the successive steps of progress by which this construction has been at last suggested, is not without interest.

Fig. 88. Fig. 89.

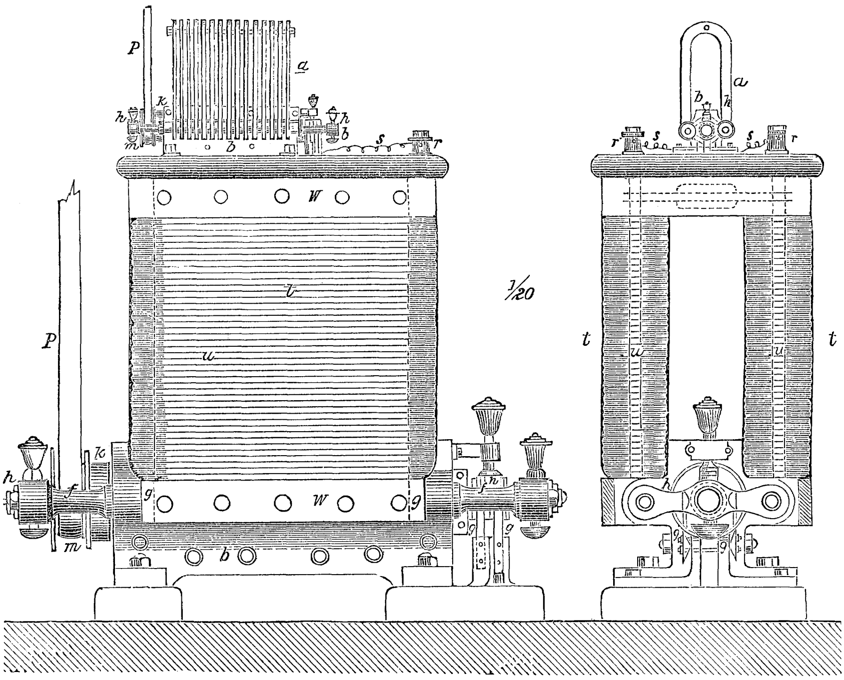


Fig. 90.

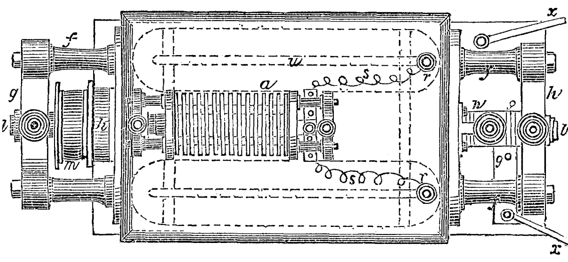
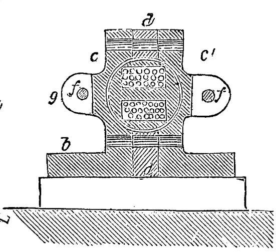


Fig. 91.



Wilde's Magneto-electric Machine

In the year 1857, Dr. Werner Siemens, of Berlin, whose name has been already mentioned above, constructed a magneto-electrical machine,

in which an elongated cylindrical armature, wound with insulated wire in the direction of its length, was made to revolve between the poles of a number of parallel steel horseshoe magnets. In the spring of 1866, Mr. W. Wilde, of Manchester, England, conceived the idea of turning the currents developed by one of the machines of Siemens upon the insulated wire envelope of a larger electro-magnet; these currents being, of course, brought into a common direction by means of a commutator. He anticipated an increase of magnetic energy, and the result justified his anticipations. The electro-magnet became powerfully excited. By rotating, next, the armature of the electro-magnet, he was able to excite to a still higher degree a second and larger electro-magnet, and in like manner a third, and so on in indefinite series.

Mr. Wilde thereupon proceeded to construct an instrument of determinate proportions and of great power, consisting of a combination of a Siemens magneto-electric machine of large dimensions with a single electro-magnetic machine greatly larger, and constructed to be used also as a magneto-electric generator of electricity. His machine in the form at present constructed by him, is represented in the accompanying figures, Figs. 88–91, and has the following dimensions:

The permanent steel magnets are sixteen in number and fifteen inches in length. They weigh three pounds each, and are capable of sustaining each a weight of twenty pounds. The armature belonging to this part of the apparatus is sixteen or seventeen inches long and about two and a half inches in diameter. It is wound with fifty feet of insulated copper wire, one-tenth of an inch in diamter. By means of a pulley at its extremity it is driven with a velocity of twenty-five hundred turns in a minute, and undergoes accordingly five thousand changes of polarity in the same time. The induced currents generated in its envelope by this rotation are turned into a common direction by means of a commutator, and sent into the wires of a great electro-magnet which forms the base on which the smaller machine rests.

This electro-magnet is formed of two soft iron plates, three feet long by more than two feet wide, and one inch thich. Each of these plates is wound with seven strands, each fifteen hundred feet long, of No. 10 wire. The total weight of the wire, exclusive of that of the iron plates, is half a ton. The plates weigh together about a quarter of a ton. These plates are placed parallel to each other, and are kept separate at one of their extremities by a bundle of iron plates, more than a foot thick interposed, through which and the great plates there pass five strong bolts, an inch in diameter, binding the whole firmly together. At the opposite end is the armature, a cylinder seven inches in diameter deeply grooved in the direction of its length, and wound with one hundred and fifty feet of insulated wire of nearly a quarter of an inch in diameter. More recently Mr. Wilde has substituted insulated copper ribbon instead of wire for this envelope. The armature turns in a hollow cylinder formed of two masses of iron separated by a mass of brass five inches thick, and bored out to a diam-

eter exceeding that of the armature by one-tenth of an inch. This hollow cylinder, bolted to the great plates at their extremity opposite to the fastening above described, forms virtually the poles of the great electro-magnet. The armature is driven at the rate of seventeen hundred revolutions per minute. The current engendered in its envelope may be employed for the production of light or for any other purpose for which electricity is needed. Its power is truly enormous. Whether any photometric determination of the intensity of the light which it produces has been made or not, has not been ascertained, but it maintains in full incandescence carbons of the extraordinary size of nearly an inch square. To drive it when in full action, a three horse-power engine is necessary.

The Alliance Magneto-electric Company of France, by whom the machines were furnished for the light-houses of La Hève, have purchased from Mr. Wilde the right to use his machines, and their power, as compared with the machines hitherto in use, will probably soon be known. In respect to weight, Mr. Wilde's machine is hardly an advance upon the old ones. Its total weight amounts to a ton and a half. The rotating parts are, however, much less ponderous, being merely cylinders of small diameter instead of huge and heavy wheels. Less of the driving force of the engine will therefore be expended against the passive resistances of friction and the air, and a greater part will probably be transformed directly into light.

When the power possessed by a magneto-electrical machine to excite magnetism in another similar machine had thus been demonstrated by Mr. Wilde, it was not a long step to take to the conclusion that the same machine would manifest a corresponding power to exalt the magnetism of its own magnets, provided the currents were turned back upon itself. This idea occurred to Mr. C. W. Siemens, of London, and about the same time to the distinguished physicist, Professor Wheatstone. Both these gentlemen have, within the present year, [1867,] communicated to the Royal in Society of London the results of successful experiments made by them in demonstration of its truth.

The forms of apparatus employed by Messrs. Siemens and Wheatstone furnished but imperfect means of deriving electric effects from the currents generated. They obtained none at all except by introducing into the circuit by which the magnetism was maintained, the objects upon which they desired the effects to be produced, and then the result was comparatively unsatisfactory; or by splitting the current into two, and diverting the greater portion of it away from the magnet. Mr. Ladd's introduction of the second armature has removed the disadvantages attendant on either of these arrangements. The magnets receive the benefit of the full currents of their armatures, and the external work which the electricity is required to perform has the benefit of a current entirely equal. At first thought, indeed, Mr. Ladd's arrangement might appear to be only a different mode of dividing the power; in other words, it might seem that as the magnets through the second armature perform a certain

external work, this must be at the expense of the magnetism which they receive from the first armature. There is a fallacy in this reasoning. The electric force which the second armature is instrumental in developing, is the mechanical force imparted by the driving power transformed. It is the influence of the magnet which effects the transformation, but this is not exercised at the expense of its magnetism. A magneto-electrical machine in which the same influence is exercised by permanent steel magnets, is a demonstration of this. Mr. Ladd's machine has therefore reduced the production of electricity by mechanical force to the simplest, the most effectual, and, apparently, the most economical form.

CHAPTER XIV.

PRINTING AND THE GRAPHIC ARTS.

PRINTING PRESSES—COLOR PRINTING PRESSES—ROTARY PRESSES—NUMBERING PRESSES—DRESSING TYPE—PRINTING WITHOUT INK—GILDING AND BRONZING OF CHARACTERS—STEREOTYPING—SWEET'S STEREOTYPE MATRIX MACHINE—FLAMMS TYPOGRAPHIC COMPOSITOR—COMPOSING AND DISTRIBUTING MACHINES—MITCHELL'S MACHINE—GRAPHIC METHODS AND PROCESSES—PANICOGRAPHY—PYROSTEREOTYPY—LITHOGRAPHY—METALLOGRAPHY—CONTINUOUS PRINTING FROM ENGRAVING ON METAL—LITHOGRAPHIC PRINTING ROLLERS—ENGRAVING—POLYPANTOGRAPH—ENGRAVING BY ELECTRICITY—DULOS'S METHOD OF ENGRAVING—HELIOGRAPHY—PHOTO-LITHOGRAPHY—PHOTOGRAPH ENAMEL.

I.—PRINTING PRESSES.

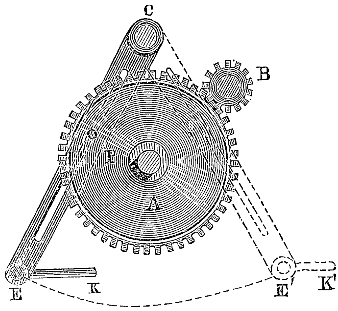
The display of printing presses in the Exposition was very fine, especially in the French section. Among these, however, were few, if any, presenting interesting novelties. That which came nearest to possessing this character was one exhibited by Mr. A. Y. Gaveaux, of Paris. This was a reciprocating cylinder press, in which the cylinder, as well as the form, receives a horizontal motion. The two movements being in opposite directions, there results an economy of space, which may, perhaps, be a compensation for the greater complication. This press has not yet been fairly tested, and to what extent the construction may be advantageous remains to be proved.

For imparting the necessary reciprocating motion to the horizontal table or bed which receives the forms in cylinder presses, three different descriptions of mechanism are employed by different constructors, or in different presses of the same constructors, all of which are possibly already known in this country. One of these, which was illustrated in the presses of Messrs. Klein, Forst, and Bohn, of Johannisberg, Prussia, and Messrs. König & Bauer, of Oberzell, Bavaria, is what is known as the movement of De La Hire, or the epicycloidal wheel. This consists, in fact, of two wheels, one of them fixed in a horizontal position to the framework of the press and provided with an interior gearing, in which there runs a satellite wheel of half the diameter carried by a crank turning on an axis concentric with the fixed wheel, while in its turn it imparts a regular reciprocating rectilinear motion to the table, by means of a pin at a point in its circumference. The motion imparted in this manner is remarkably smooth and satisfactory.

Another description of movement, introduced some years since by Mr. P. Alauzet, of Paris, has an analogy to the contrivance employed by

Mr. Ericsson for regulating the motion of the pistons in his hot-air engine, as described earlier in this report. Considering that the neatness of an impression is promoted by applying the pressure deliberately, and that time is economized by the quick return of the form after the impression has been made, Mr. Alauzet imparts the desired motion to the movable table of the press by connecting it with the free extremity of a swinging lever, pivoted at the other extremity and operated in the manner represented in the figure annexed. In this figure, CE is the lever, and C its centre of vibration. EK indicates the mode of connection with the movable table. A gear-wheel, A, has a pin P, which passes through a slot in the lever, and gives it a vibrating motion from the position C E to the position C E′. The wheel itself receives its motion of revolution from the pinion B. While the point P is describing the lower part of its revolution, the motion of the lever, as is obvious from an inspection of the figure, is comparatively slow. This is the period of impression, the motion being in the direction from E toward E′. During the remainder of the revolution, P describes the upper portion of its course, which is materially shorter than the other; and this is the period of return from E′ to E.

Fig. 92.



Alauzet's Printing Press.

Another form of mechanism for producing the necessary reciprocating motion in presses constructed on this principle, consists in a pair of horizontal racks with their teeth vertical and facing each other, which are alternately acted upon by a pinion less in diameter than the space between the two. These racks being connected with the movable table of the press, give to it a motion which is direct or reversed according as one or the other is in gear with the pinion. In order to permit this alternation to take place, the arbor of the pinion has in it a universal joint; but it is a consequence of this construction that the rotation of this arbor, which in the fixed portion is uniform, is subject, in the part which carries the pinion, to a periodical irregularity, causing slight differences in velocity of movement between the type and the cylinder, which are unfavorable to clearness of impression. Notwithstanding this disadvantage, the mechanism here described has long been in use in the power-presses of all countries. A recent improvement by Mr. Normand, of Paris, has corrected the irregularity, and given to this mechanism, which, for rapid printing, is preferable to either of those above described, a greatly increased value.

In order to understand this improvement, it is necessary to consider the cause to which the periodical inequality above spoken of is owing. The universal joint, commonly called Hooke's joint, in England, and Cardan's joint in France, may be conceived of by supposing the adjacent

ends of the two arbors which it is to unite to be provided each with an attachment in the form of the semicircumference of a circle firmly connected with the arbor by its middle point, and both pivoted by their extremities to the arms of a rigid equal-armed cross. If the two arbors are in the same straight line, they will revolve together with equal angular velocities; and the semicircumferences will generate in the revolution the surface of a sphere. If, however, the arbors are inclined to each other at any angle, each will generate the surface of a hemisphere, and the bounding circles of these hemispheres will intersect at an angle equal to that made by the arbors. Supposing the arbor to lie in a horizontal plane, and the movement to begin when the plane of the semicircle on the driving arbor is vertical, the angular velocity of the arbor which is driven will be for the moment less than that of the other. Let the upper extremity of that arm of the cross which is vertical in the position assumed, be called A, and that extremity of the horizontal arm which in the order of movement follows this, be called B; then, while A advances through any small angle, φ, B will describe a lesser angle ψ. This will be evident by supposing a great circle of which B is the pole to pass through A. This circle will cut off from the two bounding semicircles of the two hemispherical surfaces above described a right-angled triangle, of which φ will be the hypothenuse, and an arc equal to ψ the perpendicular. Also, the angle between these two sides will be the angle made by the two arbors, and may be represented by ω. This construction gives immediately,

$$\text{Cos } \omega = \cot \varphi \tan \psi \text{; or } \tan \varphi \cos \omega = \tan \psi.$$

So long as cos ω is less than radius, therefore—that is to say, so long as there is any inclination between the arbors—tan φ will be greater than tan ψ. When ψ becomes equal to 90°, both tangents become infinite, or $\psi = 90^\circ$ also. In the second quarter of a revolution, ψ exceeds φ, and the two arcs become equal again at 180°. The relative values of the two angles in the third quadrant correspond to those in the first, and those in the fourth to those in the second. It appears, therefore, that when the point which we have called A is in its highest or in its lowest position, the angular velocity of the driven arbor is at its minimum; and that when this point is in the horizontal plane passing through the arbors, the same velocity is at its maximum; the velocity of the driving-arbor continuing in the mean time to be uniform. There is, accordingly, an intermediate point in every quadrant at which the two velocities are equal. The improvement of Mr. Normand consists in giving to the pinion which moves the table of the press a figure departing from the circular by a law corresponding to that which governs the angular velocity, in such a manner that, when this velocity is above the mean, the radius of the pinion which is at the moment engaged with the rack is to the same degree below the mean, and *vice versa*. The rectilinear velocity transmitted to the table is, therefore, uniform. The figure

of the pinion is approximately but not exactly elliptical. It remains only to be observed, that in order to give steadiness to the pinion, the racks into which it gears are made undulating, being depressed where the longer radii come into action, and elevated to meet the shorter.

This form of movement was illustrated in the Exposition by very fine presses of Mr. Alauzet, and others of Messrs. Perreau & Co., of Paris. One of the presses of Mr. Alauzet was what is called by the French a reaction press. By this it is meant that the cylinders turn alternately in opposite directions, and that impressions are taken both in going and in returning. These presses are made with two, four, and six cylinders, throwing off from four to eight thousand sheets per hour.

COLOR PRINTING PRESSES.

Messrs. Koenig & Bauer, of Bavaria, mentioned above, exhibited an interesting press designed for printing in two colors at one operation; an effect accomplished by passing two forms successively under the same cylinder. The cylinder accordingly makes two revolutions before giving up the sheet. A press of similar description was also exhibited by Mr. Dutartre, of Paris. In one of these machines an expedient was employed to secure perfect equality of pressure upon the two movable tables on which the forms repose, or to increase the pressure upon one in case a larger or more continuous surface of type should require it, consisting in a construction resembling a pair of wedges reversed upon each other. This permits an elevation or depression to be made in the most gradual manner, without in the slightest degree disturbing the level. In a press of Mr. Dutartre, designed for printing works of elegance, the cylinder admits of being thrown out of gear, so that the same sheet may be twice impressed before being removed. In this machine the inking-rollers are driven by a system of wheels, and not by the pressure of the type.

ROTARY PRESSES.

Rotary or continuously acting presses, in which the form is adapted to one cylinder and the pressure is applied by another revolving against it, were exhibited by Mr. Alauzet, Mr. Marinoni, and Mr. Derriey, all of Paris. The last two exhibitors presented presses with two type cylinders, which were, therefore, also *presses à retiration*, or designed to print the sheet on both sides before giving it up.

No foreign presses constructed on the continuously rotary system have yet, however, equalled those of the originator of the system, Mr. Hoe, of New York. It was a subject of regret that none of Mr. Hoe's presses were on exhibition in the Exposition. Presses constructed in his own workshops are now in use in many of the principal newspaper offices of Great Britain, and have long been so. It is an interesting fact in the history of this subject, that, on the first introduction of these machines into England, English workmen were employed by most purchasers in

their construction; but that, after some experience with these, they were found to perform so much less satisfactorily than those constructed by Mr. Hoe himself, as to leave the monopoly of the market almost exclusively in his hands.

THE BULLOCK PRESS.

The most remarkable, however, of all printing presses hitherto invented is one which was not present in the Exposition, and which was unknown to the reporter until after the preparation of these notices had been completed, and after his return to this country. This is the "Bullock press," so named from the inventor, the late William Bullock, of Philadelphia. Like the Hoe press it carries the forms upon the cylinder, but it differs from that press in requiring no attendants to feed it, and in delivering the sheets printed on both sides. It is a great improvement also, realized in this press, that the sheets are delivered silently, the noisy racks of the Hoe press being wholly dispensed with.

The substitution of an automatic system of feeding for hand-feeding, which is one of the greatest economical advantages of this press, has been effected by introducing the paper into the machine, after it has been subjected to a moistening operation, by passing through a shower of fine spray, in the form of an endless roll. A single roll will contain several thousand sheets, and the printing operation, including the cutting of the paper into proper lengths, will proceed uninterruptedly until the roll is exhausted.

In the following extract from the Scientific American of December 7, 1867, the advantages of this press are more fully set forth:

"The operation is very simple. The roll of paper having been mounted in its place, the machinery is started, unwinds the paper, cuts off the required size, prints it on both sides at one operation, counts the number of sheets and deposits them on the delivery board, at the rate of eight thousand to fourteen thousand per hour, or, counting both sides, at the rate of sixteen thousand to twenty-eight thousand impressions. The labor is only that of placing the rolls on the press and removing the printed paper, which ordinary hands can do.

"We have seen some most excellent book printing done on the Bullock machines, which are at work in the government office in Washington. They are also employed in some of the prominent newspaper offices in Philadelphia and New York. At the Sun office, in this city, the Bullock presses have been in use for a long time in turning out the immense daily edition of that paper. Two more presses, the same kind, but of an enlarged and superior pattern, are now being introduced there.

"The Bullock press promises to effect a considerable revolution in the art of printing. * * * Its capacity for the rapid production of printed sheets is unequaled. Its first cost is comparatively small. But a small place or room is necessary for setting it up. The largest size

is eleven feet long, six feet wide, and seven feet high. Only two hands, common laborers, exclusive of pressmen, are required for its management. Being simple in construction it is not liable to get out of order, and can be easily repaired.

"We have seen an official report, by O. H. Reed, superintendent of the press room in the Government Printing Office at Washington, made to John D. Defrees, Congressional Printer, in which he shows that it would require eighteen of the Adams presses to do the same amount of book-work now being executed on a single Bullock press; and that the use of this press effects a net economy of $375 a week, over such Adams presses. The Bullock press prints two hundred thousand octavo pages in a single hour. It runs with great steadiness and uniformity, and the number of spoiled impressions averages only about one-tenth of one per cent. The estimated average of spoiled sheets on the common fast newspaper presses is between one and two per cent. The ordinary presses require of the paper manufacturer that before delivery he shall cut his goods into sheets, count, wrap, and tie them up, in separate bundles. All this consumes much wrapping paper, twine, and time, which is saved by the use of the Bullock press, as the paper is delivered in rolls just as it naturally issues from the paper-making machine, and the paper-maker is enabled to supply paper for these improved presses at from one to two cents a pound cheaper than ordinary paper. The Bullock press prints with a perfect register, and for newspaper work this is important, as it permits the reduction of the blank margin of the sheet, and thus saves paper.

"Altogether, the advantages and economies in favor of these new machines are so great that, in many cases, printers might, by adopting them, be enabled to throw away their present cumbersome presses as old iron, and make a very large annual profit by the operation. Think of saving $5,000 on the press-work of a single job. This is the statement from the government office in reference to the printing of the volume of the Agricultural Report, which was printed on a Bullock press."

The New York Herald, the New York Democrat, and the Philadelphia Democrat, as well as the New York Sun, mentioned above, are now printed on the Bullock press; and it is probable that this great invention, which has given universal satisfaction wherever it has been introduced, will soon, for rapid printing, supersede every form of press at present in use.

NUMBERING PRESSES.

Presses for printing numbers upon bank notes, railroad tickets, bonds, &c., were numerously represented in the Exposition, and attracted much notice from the curious; but none of these presented anything which could be called new in principle. Some of them were designed to number objects already printed, and others to print and number simultane-

ously. In the latter case it is necessary that the numbering apparatus be sufficiently compact to form a convenient combination with the type employed in printing the body of the impression, and that it shall be truly adjusted to the same level. By a recent improvement of Mr. Derriey, the numbering rollers are prepared by casting, instead of being cut by hand, thus insuring perfect uniformity in the character. One machine constructed by this gentleman for the use of the Bank of France in numbering its notes, presents some features of special interest. Each note receives five impressions from the machine at once, distinctive of its relations to the remainder of the issue. One of these is simply its number of order, and increases from note to note; the others are significant of the class or of the particular series to which the note belongs, and change with the commencement of each new series. But the ingenious part of the contrivance is that by which it is made entirely automatic, taking up each note separately from the supply on one side, transporting it to the printing table to be stamped, and subsequently removing it and depositing it in the receptacle for finished notes. The notes are lifted by a gentle force of aspiration or exhaustion, acting through a hollow plate perforated on the under side, and having a regular succession of movements. The exhaustion is produced by a small air pump.

Other applications of this ingenious principle have been elsewhere noticed in this report.

DRESSING TYPE.

An illustration of the fact that serious difficulties in the progress to perfection of the most important of the arts of industry are often found in matters of detail which escape the popular notice, is afforded by a machine presented in the American department by Mr. P. Welch, of New York, for dressing the surfaces of type. The types, as they come from the mould, have certain irregularities which require to be removed; and in removing these it is of the highest importance that the perfect parallelism of the opposite surfaces should be preserved, as well as the exact equality of depth in the direction of the character, so that, as set in the form, they shall constitute a perfectly compact mass. This finishing of type has never heretofore been conducted by any process insuring precision. The method universally practiced has been to rub the pieces of metal by hand upon the plane surface of a stone, employing also as auxiliary a scraper or file. The operation is wanting in expedition, and is attended with loss, since many types are inevitably spoiled in the process. The invention of Mr. Welch has entirely superseded the necessity of further using so rude an expedient. The types are supplied automatically and finished with great rapidity and the most perfect uniformity.

Some notion of the manner in which this machine operates may be gathered from the following statement, transcribed from a newspaper report of an occasional visitor to the Exposition:

"Mr. Welch sets his rough type in lines intersected by strips of brass, and composes a square block of type to be operated upon by the machine. The dressing-machine passes each single row of types between a pair of knife-blades, set exactly parallel to each other, and ground rectangular or taper, as the case may be, for the production of square type or pyramidal type, the latter suitable for being set up on a cylinder for a roller printing-machine. The type, being pushed through between the fixed cutters, remains in a straight line, while the brass strip, now no longer wanted, drops through an opening into a box below the table. The different rows of type being dressed on two parallel sides, now form a square block without partitions, and can be divided into straight lines in the second direction, presenting the two still undressed edges to the action of the cutters. They are then passed through the machine a second time, and come out finished and set up complete, ready for the use of the printer. It is well worth seeing this cleverly designed machine, with its excellent workmanship and thorough mechanical construction of all its details, and to watch its operations as it goes on with regularity and precision, doing one day's work of a practiced hand in about one hour, with greater regularity, less waste, and a better quality of work produced."

It will occasion no surprise to state that Mr. Welch received for this invention a gold medal, the only recompense of the first order given to his class, when it is remarked that the object which he has so successfully accomplished has been unavailingly pursued more or less constantly by many ingenious men before him ever since movable type began to be used.

PRINTING WITHOUT INK.

A little machine designed for printing letter-heads, visiting cards, and other such small affairs, exhibited by Mr. Leboyer, of Paris, attracted an attention out of all proportion to its importance, in consequence of the fact that its impressions are made without the visible use of ink. It is but a mechanical application to typography of the principle of the reporter's multiple writer, referred to further on, in speaking of Flamm's typographic compositor. The ink, or the coloring matter which answers for ink, is contained in a thin sheet of porous paper, which is introduced between the type and the card or paper on which the impression is to be made. The machine itself is a greater curiosity in a mechanical point of view than its performance in a chemical. In dimensions it is but about two feet by one in plan, and a foot and a half in height; and the celerity of its operation is so extraordinary that it throws off not fewer than one hundred cards per minute.

GILDING AND BRONZING OF CHARACTERS.

The bronze letters and figures upon the bonds of the United States, and other similar prints, are produced by applying the metal in fine

powder or dust to the surface of the letters as freshly printed with ordinary printing ink, or with drying oil simply, and brushing off the excess. This operation is ordinarily performed by hand, as at the Treasury Department of the United States, and is accordingly by no means rapid. A machine was exhibited in the French department of the Exposition for doing the same thing mechanically and with great rapidity. This machine consists of a cylinder completely enclosed in a box, with the exception of an opening for the introduction of the sheets. The sheets are seized by metal fingers attached to the cylinder, as in a printing press, and brought by the revolution into contact with a second cylinder constructed of elastic material, of which the lower surface is immersed in the bronzing powder. After passing this cylinder, a revolving brush removes the excess of powder, and other cylinders compress the sheet and give smoothness or polish to the metallic coating.

II.—STEREOTYPING.

It has added incalculably to the value of the Hoe press that a process of rapidly stereotyping cylindrical forms, adapted to their cylinders, has come into use within the past ten or twelve years, by means of which a number of distinct advantages have been simultaneously secured. It was, in the early history of this very ingenious machine, one of the most difficult mechanical problems connected with it to secure firmly to the great cylinder the ponderous "form" embracing the matter to be printed. This form, being made up of many thousand separate pieces of metal, required to be securely "locked," as, in case there should be anywhere any looseness, the type thus imperfectly secured were liable to be thrown out by the centrifugal force. The "chase," therefore, (or iron frame employed to hold the form,) was a subject of much study, and many expedients were successively devised to expedite and perfect the modes of locking up the forms. It would seem that as the outer surface of the form, or the type-face, is a part of a larger circle than that occupied by the base, therefore the ordinary type with parallel sides could not be used on the Hoe press. This, however, is an error, at least when the length of the lines in the pages or columns is not greater than three or four inches, as is generally true of newspapers. By giving a certain amount of bevel to the rules dividing the columns, and to the "furniture" of the chase, the requisite compactness of the mass may be obtained; and although the faces of the type will not be mathematically tangent to the circle they describe, the deviation will not be sufficient to mar sensibly the impression. For longer lines, or for smaller cylinders than those constructed by Mr. Hoe for the daily press, bevelled type must be employed.

By substituting stereotype clichés for forms of movable type, the difficulties of locking up cease to have existence. The form no longer consists of many pieces, but of one only, and it requires but a very simple system of attachments to secure it to the cylinder. Moreover, by

the great reduction of the thickness of metal in the plate below that of the form of movable type, the handling of the forms becomes much easier, and their own weight is not likely to be the cause of accidents. It is also to be taken into account that a second or a third cliché may be obtained as easily as the first; a very important consideration in the case of a publication of which many thousands have to be thrown off in the course of a few hours. Before the perfection of the invention of rapid stereotyping, the London Times was daily set up in duplicate. At present it is set up but once, and is stereotyped in triplicate or quadruplicate, the original form of movable type not being used to print from at all, but only to furnish matrices for the clichés. There follows from this the important advantage that the type undergo but very slight deterioration, so that a single font will last twenty years; when, if used in the impression of the paper daily, it would be unfit for use in less than two. And a second advantage, of almost equal value, consists in the fact that the paper is practically printed every day from new type, since the casts have all the sharpness of the original.

The clichés which have served to produce the edition of the day, are of no further use when the day is past. They may therefore be broken up and thrown into the melting pot for the morrow, so that the same metal may serve, with very little loss, indefinitely. In the short space of two hours, between three and five o'clock every morning, there are prepared from the forms of the London Times, which are corrected and turned over to the stereotypers at the hour first mentioned, three sets of stereotype plates complete for the eight pages of the paper, or twenty-four plates in all. The paper is then printed off at the rate of between forty and fifty thousand impressions per hour. In the office of *Le Petit Journal* of Paris, a daily newspaper of four pages, sold at one sou, and of which the circulation is enormous, exceeding two hundred thousand copies, six clichés are taken of each page, and as many presses are employed from four to six and a half hours in working off the edition of the day. It is evident that without the process of multiplying plates by casting, and without the rapid power-presses now in use, a limitation to the circulation of the most successful newspapers would long since have been imposed by the impossibility of further increasing the issue.

The material employed in taking impressions of type for casting, is a kind of papier maché. It was first introduced into the office of the London Times ten or a dozen years ago, but seems to have been originated independently, also, by the Paris publishers about the same time. Moulds in plaster had been previously used. They are easily prepared, but are more frail, and are slower in drying for use. The practical difficulties of preparing such moulds from curved forms, are also greater than in the case of the material by which plaster has been superseded. Stereotyping was first introduced near the close of the last century, by the publishing house of Firmin-Didot. The process originally employed by this establishment was to impress an intaglio of a page set up in type

of hard metal upon a plate of lead, and to use this as a matrix for producing the cliché. To this process succeeded another, in which the page was set up in the first instance in movable pieces, which were themselves moulds and not types. The disadvantage of this process was, that proofs could not be taken until a cast had been made, so that if there were errors to correct, it was necessary to sacrifice the first cliché, and possibly the second. The suggestion of the improvement by which casts in plaster were substituted for composite moulds in metal was made by Lord Stanhope, about half a century ago. The substitution of papier maché for plaster, which has taken place within the last ten years, has not only greatly facilitated the process itself, but has made it practicable to preserve the matrices for future use, an advantage which could not be secured with plaster moulds on account of their fragility.

Whatever the material employed in the formation of stereotype matrices, the first step in the process, hitherto quite indispensable, has been to set up the matter to be stereotyped in regular forms of movable types. In the present Exposition, the novelty has presented itself of a method of producing such matrices without this preliminary, the characters being impressed one by one in succession upon a plastic surface by means of machinery. The most remarkable machine for effecting this object which has yet appeared, was exhibited in the United States section, and is the invention of Mr. J. E. Sweet, of Syracuse, New York.

SWEET'S STEREOTYPE MATRIX MACHINE.

The machine of Mr. Sweet resembles somewhat, in external appearance, a parlor organ. It presents in front one or more banks of keys, the number corresponding to the number of characters to be employed in the work, with a few additional keys to provide for the spaces between the words. The construction may be understood by reference to the several figures of Plate VII. Fig. 1 represents a section through the middle of the machine, with the parts which are out of the plane of the section drawn in outline. Fig. 5 is a similar section in plan. In these figures the shaded parts marked A are portions of the fixed frame work. B B are keys of which the finger touches are marked b. These are pivoted near the middle of their length at b^3, and guided by upright metallic slips marked b^2. C, in Fig. 5, seen also in section in Fig. 1, is a stationary disk, perforated on its limb with a number of holes equal to the number of characters employed, through which there slide vertically an equal number of pins marked c'. Each one of these pins rests upon the extremity of one of the levers B, and is raised whenever the corresponding lever is depressed by the operator, but in its ordinary position does not project above the upper surface of C. In the centre of C is pivoted the vertical shaft D, which is free to turn, and to which is firmly attached the horizontal arm or cross-piece E. To this cross-piece is attached a bar e, which is capable of a slight movement in a vertical direction upon a pivot at one of its extremities, but which is ordinarily

maintained at its highest point, as shown in Fig. 1, by means of a spring. The shaft D has another bearing, which is not apparent, in the fixed part of the frame, and is also made hollow in its upper portion to admit the introduction of an interior concentric shaft g, which is susceptible of a vertical motion. To this interior shaft is fixed a cross-bar marked G, which passes through a mortise in D, this mortise having dimensions which admit the vertical motion just mentioned to take place, but allowing no lateral play. The shaft g, by means of the continuation i, is connected with the bent lever I, which forms a knee joint with j, by means of which the vertical rod or punch J may be depressed. The spring i' ordinarily maintains the parts in the position shown.

To the upper extremity of D is fixed a type wheel, seen in section at H, Fig. 1. Around the circumference of this wheel are arranged the types h, which are held in their grooves by means of springs h' h'. Each one of these types has a slight outward projection h^2, by means of which it is to be raised to the position shown, after having been depressed in the operation of the machine.

Upon the shaft D a pulley F runs loosely. By means of a band passing round this pulley the machine may be driven by any convenient motor. Two cams, dotted in at f and f', serve to apply the force of this pulley to the moving parts of the machine. The cam f', encountering the cross-bar G, causes the shaft g, and with it the bar G, to revolve uninterruptedly while the operator is inactive; the weight of g, i, and I, and the resistance of the spring i' being sufficient to prevent G from rising. If, however, the arm E, and with it the shaft D, is arrested in its motion, the pulley continuing to revolve will lift G by means of the cam f', the lever I will turn on its fulcrum I′, and in consequence of the straightening of the knee joint j, the punch J will be depressed. If at that moment there is a type beneath J, this type will be driven downward also, and will impress the character which it bears on its face upon any yielding material beneath it.

The operation of the machine is accordingly as follows: The operator presses down a key B by placing his finger on b. A pin c' is raised so as to intercept the arm E in its revolution. As the arm E strikes the pin, a spring which it carries drops behind the same pin and prevents recoil. The adjustment of the types on the circumference of the wheel H is such that the letter corresponding to the key touched shall at this moment stop under the punch J. The cam f', raising the arm G, depresses J through the mechanism above described, and thus forces downward the type beneath it upon the surface prepared to receive the impression.

The material employed to form the mould or matrix is paper, resembling that which is used in the manufacture of paper collars. Several thicknesses of this paper are combined, in order that the impression may have sufficient depth. Any yielding inelastic substance may replace the paper for this purpose; but as it is of the utmost importance that

the successive impressions shall not disturb or distort those which have been already made, the substance chosen ought to be one which yields by diminution of volume, and not by displacement of material. A plastic but incompressible clay or paste is therefore not suitable for this process unless indeed in the case of characters comparatively distant from each other.

The platen on which the prepared material for receiving the impression is placed is represented at P P. The prepared material is firmly secured to the platen so that it may follow all the movements which are given to the latter by the machine. So soon as the impression of one letter has been completed, it is necessary that the mould should be so far displaced as to bring a fresh surface to receive the next. The manner in which this object is accomplished is to be now described. A roller K, with ratchet groves extending from end to end, occupies the whole length of the machine immediately behind and above the finger board, as shown in Fig. 5. Fig. 1 shows the projection of the same at K. Each one of the key levers is provided with a rod b', hinged at the lower end upon the lever, but resting at the upper upon the roller K, where it receives a form which enables it to fall into the ratchet grooves, upon which it acts as a driving click or pawl. L is a two-armed lever with circular heads, M, N, shown separately in Fig. 2. To these circular heads are applied metallic bands, by means of which motion may be imparted to the lever L by the roller K, and by the lever itself to the platen P through the extension N. A band, for instance, is secured by one end at n' and at the other at n^2. Another is secured at n^4 and at n^5. There are tightening screws at n^6 and n^7 by which these bands are strained. A single band of the same kind is attached at one extremity of the lower arch head M, and passes around k', which is firmly connected with or is part of the roller K; the other extremity being secured to a sliding block m which is acted upon by a tightening screw m^3. It is by the friction of this band on k' that the lever L is moved when the roller K revolves. Motion is given to this roller as follows:

By the depression of the key lever B, the driving click b' is made to drop one or more notches upon the roller K. The number depends on the thickness of the letter which the key represents, the key B itself being arrested at the proper point by a fixed stop. The impression having been made as above described, the key B is restored to its original position by the action of the lever e, attached to E, which is depressed by the cam f of the pulley F. The cam f', by means of which the impression is produced, acts during about a quarter of a revolution of the pulley. Immediately after it has passed, the spring i', reacting upon the lever I, raises the punch J, and with it the hook j^2, which lifts the type by means of the projection h^2. This hook is secured to the punch J by means of the friction spring j', which is sustained by pins passing through J, as shown. The cam f does not act until the cam f' has completed its action; but immediately afterward it forces down e

and with it the pin c', thus setting the arm E free to recommence its revolution. The pin c', acting on the rod or driving click b', causes the roller K to turn on its axis more or less according to the distance to which the key had been previously depressed. This motion of K is imparted through the double arch head lever L to the platen, by means of the connections above described. The roller K is prevented from turning backward by the guard click s, and also from advancing too far forward by means of a friction check at the extremity opposite to k'. The platen is advanced by the movements thus described sufficiently far to be ready to receive a second letter of a word. But in case a word is complete, and a blank space is necessary before commencing a second word, the roller K may be operated on *without printing*, by means of a set of four or five keys forming a higher bank, of which one is shown at R, Fig. 1. These keys have stops beneath them, marked r^2, which striking K arrest further descent. These stops are adjusted so as to give the different spaces required in separating words or in justifying lines.

It is in the matter of justification that one of the most troublesome obstructions in the way of the rapid operation of this machine will be found. It will not answer here as in the ordinary work of composition to go on to the end of the line before spacing out the words. When the impressions have once been made, their places cannot be changed. It is necessary, therefore, to know in advance how much surplus space is to be provided for. The inventor's method of ascertaining this is the following: Each type is supposed to have a thickness equal to a certain number of elementary equal parts. The number of such elementary parts which a line will contain is found by trial, or fixed beforehand arbitrarily. Taking now the words of the copy which are to be set in a given line, we find the value of each word by adding together the separate values of its letters, and then add together these word values until we have as many as the line will receive, with allowance for space. The total, subtracted from the value of the line, will give the total amount of space to be provided for, and this divided by the number of spaces will give the value of each space. The inventor supposes that the compositor can by simple mental calculation settle this important point as he goes on. The probability of this supposition hardly needs to be discussed. At any rate, considering the possibility of occasional error in such mental computations, though they should be generally easy and exact, and considering also that errors cannot be corrected after the impression has been made, it would be safest to have the copy prepared and scored in advance.

Supposing, however, that the operator has no previous indication as to the quantity of matter which will fill in a line, he needs to be apprised when he is approaching the end; and for the purpose of giving him this information an index arm attached to the arch-head lever L and marked l^2 traverses a graduated scale as the platen advances and shows

at any moment the degree of advancement. When the line is finished, a handle affixed to the index arm l^2 enables the operator by lifting the arm to reverse the movement of the platen and place it in a position to commence a new line. In doing this, force enough must be employed to overcome the friction of the band M on k'; but it is obvious that k' might itself admit of reversal by being connected with K by means of a clamp.

It is necessary, however, that the platen should not only return through the space by which it has been moved laterally in forming the line, but that it should have at the same time a longitudinal movement equal to the distance between two successive lines. While therefore the carriage of the platen N is confined by its ways to a simple reciprocating movement, the platen itself has a second movement at right angles to this in which it is guided by similar ways, as is shown at the left hand margin *h* of the section, Fig. 1. The longitudinal movement must take place during the return of the platen, after the completion of one line, to the position for commencing another. The contrivance by which this is effected is shown in Figs. 3 and 4. Fig. 3 is the under surface of the platen. Fig. 4 presents the platen in side view, the lower surface being turned upward. This lower surface is provided with two sets of grooves crossing it entirely; one set being at right angles to its length and the other set inclined in such a manner as to connect one end of each groove of the first set with the opposite end of the next one parallel to it. The grooves are triangular in cross section, one side being vertical and the other inclined. The directly transverse grooves are deepest on the side where the line begins and considerably shallower on the opposite side. The reverse is true of the inclined grooves, which are deepest on the side where the line ends. A puppet bolt *g*, having a chisel-edge extremity adapted to the grooves, is fixed in the carriage of the platen and beneath it, and is held firmly in the groove in which it may at any time be by means of a spiral spring. This bolt is commanded at the pleasure of the operator by the handle *q*, Fig. 1. When the lateral movement commences at the beginning of the line the chisel-edge of the bolt follows the transverse groove which is there deepest. But when, after the completion of the line, the return movement begins, then it will be the oblique groove which will be followed by the edge; and as the bolt is fixed while the platen is movable, a longitudinal motion is the consequence, equal to the distance between two consecutive grooves. If this is the distance required for the commencement of a new line, the work may immediately proceed. If not it is indispensable that it shall be at least an aliquot part of that distance. Suppose, for example, that a second line is required to be formed at a distance from the first represented by double the space between the successive grooves. In this case the required distance may be secured by moving the platen forward and back by means of the handle l^2; but this would not be possible if the distance required were only once and a half the same space.

The machine, to answer the exigencies of the art, ought to admit of having its types changed so as to substitute a smaller or a larger set for those immediately in use. In this case every change of font would require a change of platen; and a simultaneous change of all the stops of the finger keys. In a large establishment a separate machine for each font would be preferable.

The rapidity with which moulds may be formed by this machine is very remarkable; provided that the copy has been scored in advance, this rapidity is measured only by the celerity with which the operator can touch the keys. The casts or clichés produced from these matrices are not yet, at least in the specimens exhibited, so sharp as could be desired. This may be owing to the imperfection of the material of which the matrices are formed, and since the invention is in its infancy, its capabilities cannot fairly be judged by its present performance.

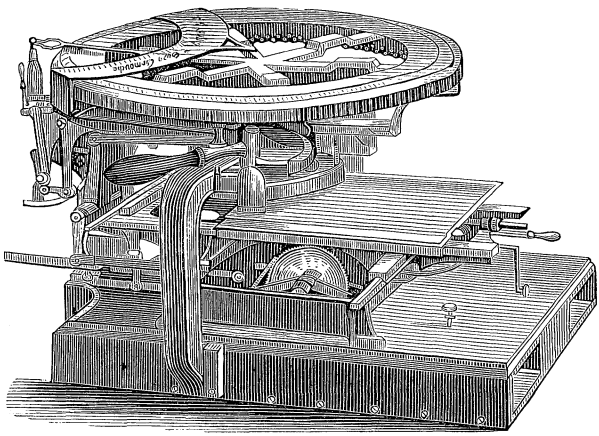
It is a disadvantage which may limit a usefulness promising otherwise to be very great, that the matrix when once formed admits of no correction, or at least of no correction which shall involve any displacement of the words allowed to stand. Means might undoubtedly be devised for removing and replacing a line or word, provided the matter inserted should occupy no more nor less room than that for which it is substituted. The consequence is that much of that alteration and amendment which authors are accustomed to defer until they see their productions in print, must be entirely completed in the manuscript, or the machine will be unavailable for original publications. There are few writers who cannot accommodate themselves to this necessity in regard to the bulk of a given work. As to those parts which *must* be printed before they can be perfected, it would not probably be a very serious matter to sacrifice the first casts of such pages and construct the matrices anew.

The machine of Mr. Sweet cannot as yet be said to have been brought to such a state of perfection as to justify the expectation that it will immediately come into general use; but it embraces the germ of a very important improvement, and there can be little doubt that the art of printing is destined to derive large advantages from it in some form hereafter. Should it become possible to prepare stereotype plates without the necessity of setting up the matter first in movable types, a very large reduction might at once be made in the amount of stock and furniture required in all great publishing establishments. Printing offices would be vastly less encumbered than at present with the quantity and bulk of their material; and the amount of capital which would be necessary in order to keep alive an industry of given magnitude would be correspondingly diminished. These advantages are quite independent of the more obvious ones, which consist in reaching a given end in briefer time, with less labor, and with fewer intermediate steps than before; and in substituting for the fatiguing labor of composition with movable types, as at present practiced, which requires the compositor to stand from morning till night, the very light task of touching the keys of an instrument while sitting at his ease.

FLAMM'S TYPOGRAPHIC COMPOSITOR.

A machine somewhat similar to that of Mr. Sweet was exhibited by Mr. Pierre Flamm, of Phlin, department of the Meurthe, France, of which the general appearance is here shown. Taking advantage of what has been said of the former one, this may be described in few words. It has a type wheel, like that of Mr. Sweet, and the types are depressed by a punch as in the same. The impression is received upon a plastic substance, designed to form a matrix. This substance is fixed upon a platen which has two movements at right angles to each other. The principal practical difference between the two machines is, that the one is all but entirely automatic, while the other is only partially so. In the machine of Mr. Flamm, the type wheel is turned and the punch is depressed by the hand of the workman himself. The transversal movement of the platen—that in the direction of the line—is effected by turning a screw. But this movement in actual work becomes automatic. As the platen moves, an indicator needle moves also along a divided arc, showing the progress made by the platen. A certain division of this arc is fixed upon to serve as a starting point for the beginning of each line, and another more advanced division to show the end. When the needle is at the first of these limits, the operator turns the type wheel with his right hand. The upper surface of this wheel is inscribed along its limb with characters corresponding to the types; and these are so placed that, whenever any one of them is brought to a line of verification under the operator's eye, the type proper to that character will be under the punch. With his left hand the operator then depresses a lever, which acts upon the type through the punch, and the impression is made. As the lever rises, the platen advances through a distance dependent on the breadth of the letter impressed. This movement is automatic. The operator then turns the type wheel again, and so continues the process. Mr. Flamm appears to have originally intended to make his machine more entirely self-acting. In his first constructions he employed keys; but the manner in which he proposed to operate by them is not understood. In a note to the writer he says: "The first machines made by me were constructed

Fig. 93.



Flamm's Typographic Compositor.

with a key-board; but I was in error in believing that the key-board is the expression of celerity."

Mr. Flamm has the same difficulty as Mr. Sweet with the matter of justification. His mode of proceeding is, after he has advanced in the line as far as he thinks it safe to go, to continue the composition *without printing*, until the needle indicates as near as possible the end of the line. He thus discovers, by actual trial, how much space he has to dispose of between the words which he has passed over but neglected to print, and then, starting from the end of the line, he prints these words, properly spaced, backward.

The platen is then returned to its original position and is moved longitudinally by turning a graduated disk, which shows by its divisions the distance moved. When this distance is that which is required for the beginning of a new line, the process recommences as at first.

As an additional security against error in the movements of the platen, the inventor has introduced a second fixed platen outside of the machine, on which a point carried by the movable platen traces all the movements, so that the operator can see at any moment the line on the page and the point on the line at which he has arrived.

It will be seen that the machine of Mr. Flamm is not recommended at all by the expedition with which it operates. It is not to be supposed that an operator with this machine would impress characters with anything like the rapidity with which a moderately skilled compositor will set up movable types. Whatever advantages it may possess, however, are all embodied in the invention of Mr. Sweet, which is on other accounts also greatly superior. It argues not very much for the discrimination of the jury, that in their awards they placed both upon the same footing.

Mr. Flamm employs as the material for his matrices a kind of paste, of the nature of which we are not informed. It would certainly seem to be quite impossible to construct a matrix in the mode here practiced, letter by letter, in any kind of paste, without producing distortions, unless the spaces between the letters are made unusually wide. The material chosen by Mr. Sweet seems clearly preferable.

A very important use to which the machine of Mr. Flamm has been applied in France, and to which Mr. Sweet's is equally applicable, is the preparation of impressions in a kind of transfer ink upon transfer paper, to be impressed afterwards on stone or on a suitable metallic surface, and printed subsequently in the manner of a lithograph. The facility with which printing from stone is now executed upon a press entirely similar to the ordinary letter press, and, indeed, in a form in which metallic types and drawings or transfers on stone are combined, renders this use of these machines more likely to be immediately successful than that which has been described above. In fact Mr. Flamm's machine was first employed in this way for some time by the lithographers of Nancy and Bar-le-duc; but the fact having come to the knowl-

edge of the printers of those cities, an injunction was obtained by them against this employment of it, as being an infringement of their rights. Its success, which had previously seemed assured, was thus greatly impeded; but the injunction having been raised, it is now coming again into use.

The manner of preparing the transfers above spoken of will be understood by reference to the multiple writers so frequently employed by reporters for the purpose of preparing several copies of a manuscript at once. Thin leaves of paper, charged with a species of ink or coloring matter, are introduced between sheets of thin and almost transparent writing paper, and a stylus of metal is used instead of a pencil or pen. In the case of the machine it is the descending type which takes the place of the style, and which imprints the character upon a sheet of clean transfer paper by pressing down upon it a superposed sheet of similar paper prepared with the unctuous ink which lithography requires.

IMPROVEMENTS IN MOVABLE TYPE.

Notwithstanding the great advantages which the stereotyping process offers, in respect to economy and rapidity of production, it is still the practice of the great publishing houses everywhere to print works of especial elegance upon movable types. All improvements of such types, therefore, which tend to increase their durability, and to insure the unvarying sharpness of their impressions throughout the entire edition of a valuable work, are interesting and important. The galvanoplastic process of facing types with copper, an invention which originated in our own country, is an improvement of this description. A greater durability still has been more recently obtained by substituting iron for copper in this process; a substitution which is effected by using as the electrolyte a double chloride of iron and ammonia.

III.—COMPOSING AND DISTRIBUTING MACHINES.

COMPOSING MACHINES.

During the quarter of a century which is just past, a vast amount of ingenuity and study has been expended upon the problem of constructing a machine by which movable types may be rapidly arranged or "set up" for the press; yet, though the operation of setting up a single type is an exceedingly simple one, the proposition to arrange an indefinite number of different kinds, drawn from as many different depositories, in an order entirely arbitrary and continually varying, is one of an extremely complicated and perplexing character. A machine may easily be constructed to perform almost any determinate single movement over and over again with unvarying precision. And it is not difficult to devise machinery to execute a system of successive movements, even though they may be very numerous, provided that when the series is complete it recurs again in the same order. In all such cases, the machine when

once constructed will perform its functions automatically; like the difference machine of Mr. Babbage, which, when once set according to a given formula, will go on turning out the terms of a numerical series so long as its motion is continued. A composing machine cannot be in this sense automatic. Since the succession of the letters to be set up is independent of law, intelligence must direct their selection; and thus, whatever description of machine may be devised to facilitate the labor of the compositor, the compositor himself cannot be dispensed with. His intelligence must constantly preside over the action of the machine, and every one of its movements must be determined by some movement of his own. The aim of the inventor must be, therefore, to make this movement as small, as light, and as capable of being executed with celerity, as possible. Some form of key-board solves, as far as it can be solved, this part of the problem. It is not very difficult to contrive a mechanism which, when a certain key is depressed, shall cause a single type to be delivered from a depository containing many of the same kind. The difficult part of the problem is to cause a *series* of types so delivered to be set up side by side in the order of delivery, with their faces all upward, and without any irregularity in the relative position of the characters by inversion or turning sidewise. This, it will be easily understood, where the number of entirely independent pieces to be transported is so great, and the individual pieces themselves are so small, is a very troublesome operation.

In nearly all the composing machines which have yet been invented, the type, when set free by the keys, fall into inclined grooves or channels in which by their own weight they descend, one after another, to the receptacle or composing-stick provided to receive them. They here form a line of indefinite length, from which they are removed in successive portions to a "justifying" stick, in which they are spaced out to the proper length of lines required. A machine of this kind was exhibited at the Paris Exposition of 1855, by Mr. Sörenson, of Denmark; another by Mr. Young, of London; and a third by Mr. Delcambre, of France. This last was the only one of the three on exhibition in 1867, and, in fact, was the only machine of any kind for setting up movable types in this last Exposition.

A machine on a similar principle by Mr. Hattersley, a British inventor, has not been exposed.

MITCHELL'S COMPOSING MACHINE.

At the London Exposition of 1862, a machine was shown, which depends for the transfer of the types upon a different principle. In this, each type as it is delivered from its receptacle falls upon an endless band which carries it horizontally for a certain distance directly from the operator, or at right angles to the key-board; when it encounters another endless band at a little lower level, which moves obliquely, or in the direction of the hypothenuse of a right-angled triangle of which

the first band is the base. To this second band it slides gently down a brass shoot, and is carried forward to a point beyond the last of the parallel bands, where it is acted on by a notched wheel called the setting wheel, which sets it upright and advances it to make room for the next type. This machine was exhibited as a British machine. It is the invention of Mr. W. H. Mitchell, of London, and nothing more ingenious or satisfactory could be imagined. It is the only composing machine, in fact, which has, as yet, successfully resolved the difficult problem proposed. Its merits have been practically tested in a number of large printing establishments, in an experience now extending to some years, during which it has been constantly in use. One of the most important of these is the establishment of John F. Trow, of New York, who has had five of Mr. Mitchell's machines in operation for several years, with constantly increasing satisfaction.

DELCAMBRE'S COMPOSING MACHINE.

In all these machines the types are arranged in compact rows side by side, and in separate but parallel channels, each row occupying a channel by itself, and all these channels standing (except in the machine of Sörensen) somewhat inclined, in one plane just behind the key-board. In Sörensen's machine these channels occupy the circumference of a cylinder. Generally, the action of the key displaces the lowest type of the column and delivers it over to the contrivance for transmission to the composing stick. In Delcambre's, however, the types in each channel are pressed upward from below, and the column has a curvature at the top which brings the upper end to a horizontal position. It is the most advanced type at this extremity of the column which is dropped under the action of the key.

No composing machine can conveniently provide for all the varieties, or "sorts," of character which the exigencies of the typographic art may require. In Delcambre's machine there are eighty-eight keys, which suffice for lower-case, capital and small capital letters, with spaces and points. The other characters are provided for by means of two revolving stands, one on the right and the other on the left of the compositor. These are turned, as occasion requires, by hand, so as to bring the required sort over a guiding groove which carries it, when set free, to the common trunk. One such guide serves, therefore, for all the characters of each revolving stand. Of course, the introduction of unusual characters is not, in the use of this mechanism, an expeditious process. On the other hand, it is attended, in the long run, with no great loss of time, from the fact that it is unusual.

A fault of all composing machines as yet invented, with the single exception, it is believed, of the machine of Mitchell, is that the type set free by the different keys do not reach their destination in equal times; nor even is the time of the successive pieces from the same key quite invariable. The inclined planes are not all of equal length; they neces-

sarily cannot be all straight, and their curvatures cannot be all similar and equal. Moreover, from the varying condition of the surface of the metal, the resistance offered to gravity by friction is not constant. It happens, therefore, that whenever the keys are touched in rapid succession, an engorgement occurs at some point where different channels join the common trunk, and annoying delay is the consequence. On several occasions on which the writer of this report had an opportunity to see the machine of Delcambre in operation this accident occurred incessantly. It was no doubt occasioned by the effort to show that the machine was capable of performing its work much more rapidly than a compositor setting his type by hand; but this was the very thing which it would not do. When the keys were touched slowly, and each type had abundant time and a clear way before it, the performance was satisfactory. The moment the celerity of movement exceeded a quite moderate rate, the engorgement came on, a perfect mob of type became wedged together in the grooves, and the work of restoring order was a seriously troublesome affair.

The machine of Mr. Mitchell is free from liability to this accident. The endless bands move uniformly, and each type has the velocity of the band which carries it. The movements are so arranged that the time of travel of each type from the key to the setting wheel is exactly the same, from whatever part of the key-board it starts. No matter, therefore, with what rapidity nor in what order the keys are struck, the corresponding types will arrive and will take their places in the composing stick in the same order exactly, and without collision or confusion of any sort. The experiment has been made up to a rapidity of six touches to the second, or 21,600 to the hour, with the most satisfactory success. Practically, this velocity is unnecessary. The work of "justifying" can hardly be conveniently divided, and the machine is not required to deliver the type set up any faster than they can be justified. It is stated that two men will set up and justify 50,000 type per day, which is about twice what they would accomplish without it. It must be observed, however, that the work is infinitely more pleasant and less laborious than composition by hand.

The above may be stated as the rate of performance of Mitchell's machine. Sörensen claimed for his the same numbers. Of this, nothing positive is known. Delcambre's evidently cannot approach this, yet in his programme, without giving numbers, he states that his machine will perform in one hour the work of an ordinary compositor in four.

DISTRIBUTING MACHINES.

Every composing machine requires a distributing machine as its indispensable companion. To distribute type mechanically is a problem much less perplexing than to set them up in words and sentences. The operation may indeed be made entirely automatic. This only requires that each "sort" of type shall be distinguished from every other, by

some characteristic difference in the body. Such a difference may be provided by the following expedient. Each type in the ordinary fonts is marked on one side with notches, fewer or more numerous in different fonts, but equal in number for all of the same font; the object being to enable the compositor, by feeling as he picks up the piece, to know which side to place outward in his "stick," in order that the character may be erect. It is only necessary to vary the distances of these notches from each other, (supposing for instance that there are two only on a type,) so that no two pieces shall be exactly alike, and we have a means of mechanically identifying every individual "sort."

Let there, for example, be prepared a bit of metal having projections, or tenons, on one of its edges, corresponding exactly in size and distance to the notches on any type; these tenons will fit into the notches of that particular letter, but will fit no other. Such a piece of metal may be compared to a key, and the type to a lock which it will fit. Suppose now that a set of such keys, corresponding to all the varieties of type, are arranged side by side, their projecting tenons being all slightly pressed against a smooth plate of metal by a separate spring behind each. Let then a row of type, taken from a compositor's stick, be placed in a groove or channel in another plate of metal, so that its outer surface is flush with the plane of the plate; and let this plate be placed edge to edge with the former and used to push it aside, so that the lower type of the row (the type lying on their sides) shall pass along in front of the series of keys. So long as it passes keys only which do not belong to it, no consequence will follow; but the moment it comes opposite to its own, the tenons of that will drop into its notches. Thus the type is identified, and a mechanical movement takes place at the same time. It is a mere matter of detail to contrive a mechanism which shall thereupon release the type identified.

The above illustration is intended merely to make intelligible the general principle on which an automatic distributing machine must be constructed. The principle may be applied in a great variety of modes. In Sörensen's distributor, the type are placed in the circumference of a revolving cylinder, and are carried along by the revolution of the cylinder over a succession of apertures which have re-entering angles corresponding to the notches on the type. In this machine the type themselves may be compared to keys, and the apertures to the key-holes. Delcambre's distributing machine is not automatic. The type are placed in a long row in a channel, along which they are gradually advanced. A mirror placed behind the type enables the operator to read them; and the distribution is effected by touching a lever which displaces the last type of the row, and opens at the same time the duct or slide corresponding to the character, into which the type drops. In all the distributing machines, the type are arranged in their separate receptacles as they fall, in a perfectly regular order, so that they can be transferred at once to the composing machine. Since each description of type has its separate de-

pository, there is no danger of obstruction by engorgement, such as has been mentioned as occurring in composing machines like Delcambre's, which direct the type from many branches into one common trunk.

IV.—GRAPHIC METHODS AND PROCESSES.

PANICOGRAPHY.

The preparation of plates for the letter press from zinc by processes chemical or galvanoplastic, or both, has recently acquired considerable importance. As yet it is chiefly employed for music, designs, maps, charts, and other objects in which extreme fineness of delineation is not important. The subject to be produced is prepared on transfer paper with suitable ink, and applied to the surface of a polished plate of zinc. Fine rosin is then dusted on the ink, which gives to the lines hardness and substance. The uncovered parts of the plates are subsequently eaten out by acids, and the plate is ready for the press.

An improvement on this process is to write upon a plate of zinc with a kind of conducting ink, the plate being first coated with a non-conducting film, and to throw down copper afterwards upon the lines by means of electricity. The completion of the process consists in removing the non-conducting coat and eating out the zinc not protected by copper by making the plate the positive electrode of the battery.

Another improvement still is to coat the plate with whiting and to trace the design with a point through the coating. Varnish will then adhere to the uncovered metal, but not to the whiting. This latter may then be washed off, after which the parts of the plate uncovered by varnish may be eaten away as above by acids, when the design will remain in relief and may be printed from.

The best example of the successful application of panicography to printing from the letter press seen in the Exposition, was the specimen of the geological map of France exposed by the *Imprimerie Impériale.* This, though embracing but a limited portion of the entire map, was of very large dimensions, covering not less than one hundred and twenty square feet of surface, and was most admirable in point of beauty and finish. Seventeen different colors are employed to indicate in this map the various geological characters of different parts of the territory, and each of these colors requires a different plate and a separate impression. Several of these plates are prepared of zinc by the processes above described.

PYROSTEREOTYPY.

Others are produced by a process called "pyrostereotypy," which consists in preparing a matrix by a peculiar process of burning it into wood, and then taking a cast of it in an easily fusible metal. In this operation the first step is to trace the design upon the surface of the prepared wooden block. The block is then placed before a machine

tool of peculiar construction, the essential part of which is a delicate blade of metal capable of being alternately advanced and withdrawn with rapidity. A jet of flame directed across this implement heats it to redness, and in its rapid thrust it burns away the wood before it, leaving a perfectly sharp incision. This process of engraving is not, of course, adapted to the production of lines of extreme delicacy, but the beauty of its results, as shown in the geological chart, is as undeniable as it is surprising.

LITHOGRAPHY.

The original lithographic press, commonly called the scraper press, is now generally abandoned. Very few presses of this kind were seen in the Exposition. A number of roller presses were exhibited, and were usually kept in operation in printing various designs in colors.

In the roller presses at first introduced, the pressure was applied by means of levers and heavy weights to avoid accident to the stone from an unyielding resistance in case of any irregularity of adjustment. At present these weights are dispensed with, but a certain elasticity is given to the bearings of the cylinders by strong springs of metal, caoutchouc, gutta-percha, &c., placed behind them, or the same object is attained by placing similar yielding materials beneath the stones. The stone is adjusted to the proper level by means of screws or wedges beneath the bed-plate, or by a bed-plate of a wedge shape resting on a second one of similar form reversed, a construction which serves to expedite the adjustment, while it maintains the horizontal position of the bed unaltered.

It would be but a moderate advantage to substitute the roller for the scraper, if it should still be necessary to continue to work the press by the unaided strength of men. In its present form, however, the lithographic press is as nearly automatic as the letter press. The stone is supplied with water as well as with ink by rollers, and the task of the attendants is limited to supplying and removing the sheets.

Messrs. Kocher & Houssiaux, of Paris, exhibited a press in which the roller is itself the stone bearing the design to be printed. Some advantages are gained by this construction in point of compactness, and also in the facility of applying the water and the ink. It would also be an advantage still greater that the printing by means of a roller could be made continuous, so as to be employed for producing wall paper, &c.; but a serious difficulty in the way of its general introduction arises from the rarity of occurrence of homogeneous masses of lithographic stone of sufficient size for the purpose. In view of this difficulty, the constructors above-named have turned their attention to the attempt to supersede stone for the uses of this art by means of some metal possessing analogous properties in its relations to oil and water. In this they claim to have succeeded, but the success is apparently not yet entirely satisfactory. An account was published in 1866 in the *Génie Industriel*

of Paris, of the experiments of these gentlemen in this direction. From this account it appears that the metal employed by them is tin reduced to the form of thin laminæ or tin foil. In their first experiments the tin foil was attached by glue or paste to a very smooth pasteboard, and the sheet thus prepared was stretched upon the cylinder of the press. But the cardboard was not sufficiently resisting to sustain the pressure long, though in other respects the results left nothing to desire. They then employed ordinary sheet tin (tinned iron) in place of the cardboard, and afterwards tinned copper, but neither of these proved durable, and they were abandoned. The substitute which was finally found to be successful is an alloy of lead and antimony, something like type-metal. Sheets prepared with this material for a backing, and with tin for the printing surface, are represented by the inventors to fulfil all the necessary conditions.

In order to attach securely the metallic sheet to the cylinder, there is a narrow opening or slit, extending along the whole length of the latter, which is hollow, and through this opening one edge of the thin plate is introduced. This edge is seized and clamped by suitable jaws; when the other end, the sheet having been wrapped around the cylinder, is inserted through the same opening, and having been similarly seized, is strained round a longitudinal rod which may be turned from without, and which is prevented from recoiling by a ratchet. Should this mode of chemical printing prove to be successful, it will possess several important advantages over lithography. The sheets being thin and light will be much more convenient to handle than stones. As they admit of being rolled, they will occupy much less space and will less encumber the locality. It will be much more convenient to stow them away in case the designs are to be preserved for future use, and to have them easily accessible when wanted. They will be comparatively cheap, costing only according to their weight, while their total weight is much less than that of stone; whereas stones of large dimensions are disproportionally expensive. They may be constructed of any size, while to the possible size of lithographic stones there are natural limitations, and the rare occurrence of very large masses presenting surfaces of uniform character in this material practically restricts these limits very essentially. These are great advantages; but more than two years having elapsed since the publication above spoken of without having secured for the improvement a recognized place in this important branch of industrial art, it is to be presumed that the anticipations of the inventors have not been fully realized.

In the catalogue of exhibitors as at first prepared there appeared the name of another projector of Paris, who proposed to himself the same problem which had occupied Messrs. Kocher and Houssiaux, as above described, viz, that of chemically printing from metal. His name having been withdrawn, an inquiry was instituted which elicited the information that his failure to appear had been occasioned by an unanticipated

imperfection in the mechanical construction of the machine which he had designed to exhibit. He proposed however to make, at a later period, a full demonstration of the merit of his invention in presence of the commission of the United States. But it was only a short time previously to the final closing of the Exposition that he was able to announce his readiness to furnish the proposed illustration, and no opportunity occured to take advantage of his proposition.

METALLOGRAPHY.

Mr. Verney calls his process "metallography." He proposes to print by chemical means from metal rollers. The following statements are given in his own words, (translated:)

"The chemical process employed to fix the design so as to render the reproduction possible is very simple. The preparation of the metallic surface is accomplished by mechanical means specially devised for this object. The impression can be continuous, or upon separate sheets, which allows the printing of figured papers or tissues, as well as of pictures and every species of ordinary impression. The different parts of the machine are entirely new both in form and purpose.

"The invention has been patented in France, Belgium, the United States and England. It has not been employed industrially beyond the premises of the inventor. The advantages are, besides that of continuous impression, just indicated, first, extreme simplicity; second, facility upon the same machine of enlarging the form; third, possibility of varying the forms and the different organs in such a manner as to adapt these machines to the most varied industries—to the printing of ribbons, for instance, by a machine which would not occupy more room than a sewing machine; fourth, extreme rapidity in changing the designs; fifth, noiseless movement; sixth, lightness of construction; seventh, motive power, so to say, nothing; eighth, absence of all danger to the attendants.

"The economical advantages are, in the first place, a saving of more than ninety-five per cent. in the cost of material merely. Lithographic material is expensive, bulky, very heavy, very difficult to manage, and very easy to break. This last accident involves also the loss of the design. Metallographic material, on the other hand, costs little, fills little space, is light, easily managed, not easily injured, and in case of possible injury, retains still an intrinsic value. Lithographic stones are limited in size, and beyond certain dimensions impossible indeed to find. And apart from the price, which for large stones is enormous, all the other inconveniences mentioned above become more serious as the dimensions are increased. In the case of metal there are no limits to the size, and the price is proportioned constantly to the weight. No description of this process has been made public."

The inventor explains more fully that his reason for avoiding all publicity in regard to his process, has been his desire to bring it before the

world only when every mechanical and chemical difficulty in the way of its success should have been successfully and completely solved. It cannot be denied that if his claims shall bear the test of experiment in their application to the actual uses of industrial art, his invention will prove to be, as he predicts it will, "the starting point of an entirely new impulse in this branch of industry."

CONTINUOUS PRINTING FROM ENGRAVING ON METAL.

An interesting process considered in an economical as well as in an industrial point of view, was presented by Messrs. Godchaux and Co., of Paris, in the impression from engravings executed upon metal rollers, of copies for children's writing books, made upon endless paper received from a feeding roller. The paper is impressed on its opposite sides by two rollers successively, and is then cut off into sheets by a knife resembling those used for the same purpose in the continuous manufacture of paper. After the impression the paper passes over a small gas furnace which completely dries the ink. This ink appears to be a water ink, which not only facilitates the drying, but also gives the copy the appearance of having been written with the pen; a circumstance which, considering the purpose for which it is intended, is a material advantage. The writing books, which are really elegant productions, are done up in covers of colored paper embellished or bearing instructive lessons, and a single book of twenty pages is sold for little more than one cent.

LITHOGRAPHIC PRINTING ROLLERS.

One of the greatest difficulties encountered in the early history of the lithographic art, and one which seriously, for a time, impeded its success, was the imperfection of the means available for applying ink to the stones. The printing press had long been supplied with excellent inking rollers, in the manufacture of which the essential ingredient employed is glue. But the necessity of keeping the stone constantly wet rendered the use of this material for lithography impossible. The inventor of the art, Senefelder, first made use of the old-fashioned inking ball; but the effect was not good. He adopted, subsequently, the roller; but his rollers were imperfect.

The house of Schmautz Brothers & Jacquart, of Paris, is that which at the present time produces the rollers most approved by lithographers, and supplies most of those in use in the principal cities of Europe. The founder of this house, and the father of the brothers Schmautz, may be said to have been the first to bring the manufacture to a condition at all satisfactory. A note from these gentlemen supplies some entertaining information connected with the history of this subject. They write:

"The Count de Lasterie, who founded the first *lithographie* in Paris, imported his rollers from Germany. They were covered with a very thin leather, as thin as a kid glove, and lasted but a little while—about three months. This very delicate leather, sewed over and over, made a seam

too prominent, which marred the inking. When the seam began to fail it was the *femme de chambre* of *Madame la comtesse* who was charged with the duty of repairing them with her needle. This not very agreeable task led her to look around for some one to do it for her; and the father of the writer, who was then a working shoemaker, living in the same building, 4 St. Germain street, commenced repairs, which soon, with the aid of the advice of the Count de Lasterie, changed completely the fabrication of the rollers.

"He caused leather to be prepared expressly for this work, stronger, yet quite as soft as before, and replaced the seam by a juncture of the edges. Then, instead of nailing the leather on the ends, he punched holes and passed through them a double cord, which allowed the leather to be tightened or loosened according to necessity, and the nails no longer wounded the hands of the printers. The roller was, therefore, finally born. The reputation of this roller was promptly spread abroad, and soon Germany, the cradle of the art, sent numerous orders for rollers to the writer's father; for the Germans found his rollers much superior to their own. Lithography rapidly spread itself over the entire world, and the promise of the Count de Lasterie, who had said in the beginning, 'these rollers are a certain future for you,' was realized.

"The writer's father tried various expedients in the hope of getting rid of the seam. He skinned the legs of calves, cows, and horses; but these skins abandoned with difficulty their conical shape, so that the rollers were loose at one end and tight at the other. He employed also the skins of dogs, which gave a better result; but the *mamelons* produced prominences, and he was compelled to give them up. A joint, firmly made and carefully managed by the printer to prevent scratching, was always greatly superior. He made, also, trials of rollers composed of disks of leather pressed between two plates of iron and turned in a lathe. When a perfectly true surface had been obtained it was applied to the ink; but these disks, however closely pressed, left their marks upon the stone. It was impossible to employ them with success. The same failure followed experiments with various glues proposed by Mr. Constant, chemist at Sèvres. The leather was cut to a bevelled edge, the two edges overlapped and united with these glues, and the joint kept under pressure till it was entirely dry; but on putting it to use it began in some days to give way in places, and soon after the whole joint failed.

"The rollers manufactured at present last at least three years, and, in the hands of a careful workman, six."

The length of this extract is justified by the light it throws upon the many difficulties which attend the progress of industrial improvements in matters apparently of the simplest nature. A great art, capable of applications of almost incalculable importance, was retarded in its early progress, not less by purely mechanical difficulties of the most seemingly trivial character of which the world knew nothing, than by the embar-

rassments inherent in the nature of the process itself, and which everybody could see and understand. The house of Schmautz still maintains the pre-eminence in its own line of production which its founder early secured for it; and its present representative is justified in the pride with which he remarks, "we believe that we can affirm that the largest part of the lithographs exhibited in the Exposition, as well of foreign countries as of France, have been printed by means of our rollers."

ENGRAVING—POLY-PANTOGRAPH.

Some processes of engraving, dependent principally upon mechanical or chemical principles, were exhibited which seem to possess sufficient interest to deserve mention. One of these was a "*poly-pantographe*," exhibited by Mr. Gavard, of Paris, in the French section. By means of this ingenious instrument a multitude of perfectly similar designs may be simultaneously executed upon a metallic plate from a single pattern. In this way may be obtained, and for many purposes quite as satisfactorily, a uniformity of impressions which is ordinarily secured only by the use of the roller die. But the peculiarity which evinces the greatest ingenuity in the construction of this machine, is its capability of tracing its multiple designs upon a cylindrical surface, though the given pattern should be plane. Rollers for continuous printing, whether upon paper or upon cloth, may thus be prepared by means of it with the utmost facility, the points of the gravers returning at the end of the revolution to the place of starting with the utmost precision, and thus producing a pattern completely unbroken. The adjustments are such, moreover, as to admit of a variation of the scale so as to produce copies either enlarged or diminished, or with unequal variations in co-ordinate directions, elongating or compressing the pattern at pleasure.

ENGRAVING BY ELECTRICITY.

Another mode of mechanical engraving was exhibited by Mr. Gaiffe, of Paris. The machine of Mr. Gaiffe consists essentially of two or more disks with their faces in the same vertical, and their axes in the same horizontal plane. One of these disks carries the pattern to be copied, the others are designed to receive the engraved copies. The graving tools are armed with diamond points and are governed in their movements by the power of electro-magnetism. Each one of these implements is in fact connected with the armature of an electro-magnet, which, when in action, prevents the tool from touching the plate, but which releases it when the current is broken, permitting the graver to take the metal. These alternations of movement are determined by the pattern-plate, on which a conducting point is constantly resting. Both the pattern-plate and the plate to be engraved are in constant revolution with equal angular velocities, while, at the same time, the tracer and the graver approach very gradually and uniformly toward their centres of motion. The combination of these effects causes the tracer to describe a spiral of very

close involutions on the surface of the plate on which it rests. During the flow of the electricity, the tracer and the pattern-plate form a part of the circuit. The current will, therefore, be broken by any non-conducting surface interposed between them. Accordingly, if a design be drawn upon the pattern-plate in non-conducting ink, the graver will be released, and will act on the metal before it every time the tracer crosses any one of the lines of the design. When the tracer has, in this manner, passed over all parts of the pattern from the circumference to the centre, a complete copy will be found to have been produced on the plate under the graver, from which may be printed fac similes of the original design, with the exception that the hair lines will be found to be made up of a succession of minute dots. It is easily seen that a multiplicity of copies may be taken simultaneously with the same facility as one. And, by the application of the pantographic principle, the designs may be reduced or enlarged in any proportion. But the method is much better adapted to reductions than to enlargements, inasmuch as, in proportion to the magnitude of the copy, the separate touches of the graver are more or less conspicuous. When these are very apparent the effect is by no means pleasing. The spiral arrangement of the minute touches becomes apparent, and the impression produced upon the mind is that of a mechanical rather than of an artistic triumph. The pattern best suited to elegant reproduction by this process is formed by taking a plate already nicely engraved and filling its lines with resin. If the pattern is large and the copy small the prints from the reductions are very pretty.

It is easily seen that reductions to different scales may be simultaneously made from the same pattern. If a series of gravers be attached to a bar, pivoted at some point in the line of the centres of motion of the revolving plates, their points being all truly in line with this pivot and and with the tracer, then in the gradual movement of this bar on its pivot, copies will be executed to scales greater or smaller, in proportion to their distance from this point.

At the Exposition of 1862, in London, a machine for engraving by electricity very similar to this was exhibited by Mr. H. Garside, of Manchester. It was said to be a French invention and may have been the same; but it was there employed only for the purpose of preparing rollers for printing tissues and paper hangings.

DULOS'S METHOD OF ENGRAVING.

Another novel method of engraving, essentially chemical, was exhibited by Mr. Dulos, of Paris, and was rewarded with a medal of gold. In this, the subject to be copied is first produced in lithographic ink upon a surface of copper. The parts uncovered by the ink are then coated with iron by the galvanoplastic process. A solvent is next employed to remove the ink, and the copper surface thus exposed is silvered by electricity. Mercury being then applied to the silver, there is formed an amalgam which presents the design in relief. From this relief a cast is taken, after which

the remaining steps of the process need no explanation. The process furnishes plates adapted to the copper-plate press or to the letter press, as may be desired. Specimens of impressions from plates thus prepared were on exhibition, and appeared to be admirably executed.

HELIOGRAPHY.

Since the invention of the pnotographic art two objects have steadily occupied the attention of those experimenters whose attention has been given more to the improvement of the art itself than to its practice as an industry. The first of these is the production of pictures presenting not merely the forms, but also the natural colors of visible objects. To a certain extent the persevering efforts which have been put forth in this direction have been crowned with success. Photographic proofs representing objects in their natural colors were exhibited by Mr. Niepce de St. Victor, a gentleman whose name, as well as that of his distinguished relative, Mr. Nicephore Niepce, will ever be intimately associated with the history of this beautiful art; but these colors are unfortunately fugitive and shortly disappear on exposure to the light of day. To have produced them at all is, nevertheless, a great step of progress. It can hardly be doubted that expedients may yet be devised by which to fix the tints which have been hitherto found to be so fleeting.

The second of the objects above referred to is that of impressing upon metal or upon stone the images of the camera so forcibly as to allow prints to be taken of them in ink, which, as it respects beauty and minute accuracy of delineation, may be in some good degree comparable to the photographs themselves. This very important object may be said to have been more satisfactorily attained. For many purposes, light fulfils perfectly the functions of the burin upon metal, or of the pencil upon stone. In the reproduction of the delicate gradations of shade which characterize the photographs of natural objects, something remains perhaps yet to be accomplished; but copies produced from actual engravings, in which such shades are imitated by the greater or less force of the lines or dots employed to express them, are so faithful to the originals as scarcely to admit of being distinguished from them.

The earliest attempts at heliography date almost as far back as the invention of the daguerreotype, and were made upon the daguerreotpye plates themselves. At this period of the history we meet with the names of Donné and Berres, experimenters who endeavored, by the use of dilute nitric acid, to bite in the dark parts of the picture; while the light parts being covered by mercury, should be left untouched. Since mercury is soluble, however, as well as silver in the acid, it results that, if the operation is long continued, the whole surface becomes at length uncovered, and the biting ceases to be differential. And if the process is arrested before this effect has been produced, the impression is not sufficiently strong to produce satisfactory prints.

Mr. Grove, and afterwards Mr. Fizeau, proposed an improvement of this

method which was attended with better success. The mordant employed by these gentlemen was *aqua regia*, but this may be replaced by a mixed solution of alkaline salts of the component acids. A chloride of silver is formed upon the darks which may be removed by solution in caustic ammonia, and the process may then be repeated. By this means an inequality is produced which suffices to enable the operator to protect the more prominent portions of the plate by electro-gilding, the depressions being preserved from the action of the battery by means of a coating of oil. After the gilding, the oil is removed by caustic alkali, leaving the copper in the depressions exposed to the action of chemical reagents, while the prominent portions are perfectly protected by their covering of gold. The etching may then be carried to any extent desired.

A defect of the plates thus produced, and it is one which still exists in those which are formed by more recent and more perfect processes when the photographs from which they are derived are such as have been taken directly from natural objects, is that the uniformity of surface upon the deep shades is unfavorable to the adhesion of the ink. To overcome this difficulty the expedient has been resorted to which is commonly employed in the preparation of aqua tint engravings—that is to say, before applying the mordant the plate is dusted over with finely powdered resin. This, by producing inequalities of action, leaves the surface sufficiently rough to retain the ink. A variety of other expedients to the same end have been introduced by more recent experimenters, none, perhaps, yet entirely satisfactory.

With this reservation, it may be said of the plates engraved by the process of Mr. Fizeau, that the prints which they furnish are excellent; but the softness of the metal restricts very much their durability, and they allow but few copies to be taken. They may be made more lasting by being coated electrically with copper; and with this improvement no doubt they would continue to be used, but for the fact that more recent and less uncertain methods of operating have superseded this one, and left to it only a place in history.

The processes at present in use, which are considerably varied, depend upon one general principle, which is to spread over a plate of metal a thin coating of some substance which, from being originally soluble, is rendered insoluble by the action of light, and which, in its insoluble state, resists the action of acids. Two substances of this character have been found which answer the purpose sufficiently well. The first is mineral pitch, asphaltum, or *bitume de Judée*, as it is called by the French; and the second, gum, gelatine, or a mixture of both, to which has been added a certain proportion of the bichromate of potassa. The first of these materials was early employed in experiments on heliography by the elder Niepce, and it has since been very effectually used by Niepce de St. Victor and Mr. Charles Nègre. Mr. Nègre employs plates of steel, and after the first application of the mordant, covers the salient parts with gold, as in the process of Mr. Fizeau, above described.

The use of the gelatine-bichromate was first suggested by Mr. Fox Talbot, the originator of photography upon paper, early in 1852. It is the basis of the processes now in most general and most successful use. Among those whose prints, obtained in this way, have been most admired, may be mentioned Messrs. Garnier, Placet, Pretsch, and Baldus, all of whom were exhibitors in the Exposition. Mr. Garnier presented a photographic view of the chateau of Chenonceaux side by side with a heliographic print taken from the same photograph, and with the plate from which it was printed. It would be difficult, without close examination, to distinguish the print from the original. Mr. Placet exhibited specimens of heliographic portraits which were distinguished for their remarkable beauty and finish. It is especially in this branch of the art that hitherto the greatest difficulties in heliographic engraving have been met with. Mr. Garnier's plates are executed upon copper, which he protects by coating them electrically with iron. For this improvement, applicable also, as elsewhere stated, to the hardening of the surfaces of ordinary types, and for the high degree of practical perfection to which he has brought the art of heliography, Mr. Garnier was rewarded with the signal distinction of a *grand prix.*

Another and simpler process by which very fine results are produced, was illustrated in the prints exposed by Messrs. Tessié de Motay and Maréchal. In this process, the gelatinous coating of the plate is hardened by heat before exposure. It acquires thus a firmness sufficient to bear the pressure necessary to print from it directly. By soaking it in water after it has received the impress of the image, the parts of the coating unaffected by light swell up, while the others remain unchanged. These last take the ink from the roller, but the softened portions, being full of water, repel it. It follows that the photographic impressions must be made upon the plate by a negative. Plates prepared in this way are not very durable, a single one furnishing upon an average not more than seventy-five good impressions. On the other hand, the simplicity of the process of preparation permits their indefinite multiplication.

PHOTO-LITHOGRAPHY.

The process just described can hardly be called heliography. It is analogous rather to what is called photo-lithography. This process is founded on the property already mentioned, of the bichromatized gelatine, and dates back as far as to the year 1855, when it was patented by Mr. Poitevin. As a means of copying line drawings and engravings, or printed or written documents, or maps, or charts, or any other devices which present no half tints, this art has become firmly established in industry, and has acquired a very sensible importance. The manner of preparing the stones for impression differs with different operators. By some, the sensitive coating is applied to the stone directly; by others, a proof, first obtained upon paper, is afterward transferred to

the stone in the manner familiar to lithographers in the ordinary practice of their art.

PHOTOGRAPH ENAMELS.

As naturally connected with the subject of heliography, a word may here be added in regard to the process, now so successfully pursued, and of which the results are so pleasing, and even brilliant, of transforming photographic plates into enamels, preserving all their original delicacy and beauty, and enriched by the addition of the most varied colors. Two methods are employed in the production of these colors. In the first, introduced and applied with remarkable success by Mr. de Camarsac, of Paris, colored vitrifiable powders are applied with the pencil to the different parts of the proof on glass, and the whole is raised to the necessary heat in a muffle. In the second, that of Messrs. Tessié de Motay and Maréchal, of Metz, the photographic proof, taken in the ordinary way, but made as forcible as possible, is immersed in solutions of other metals by which the silver is displaced. If this be done successively in several baths, with exposure of different parts of the device in each, the subsequent process of enamelling will furnish corresponding varieties of tint. Some of the transparent enamels exhibited were of very large dimensions, a single subject being sufficient to fill an entire window. As compared with any of the stained-glass designs seen in the windows of churches and cathedrals, their vastly superior delicacy and beauty is obvious at a glance.

THE EXACT SCIENCES.

CHAPTER XV.

GENERAL VIEW OF THE EXPOSITION IN CLASS TWELVE.

COUNTRIES CHIEFLY REPRESENTED IN THIS CLASS—THE FRENCH SECTION—FORMS OF APPARATUS WHICH ARE NEW—THE AMERICAN SECTION—MODEL BALANCES OF THE UNITED STATES—BARLOW'S PLANETARIUM—BOND'S ASTRONOMICAL CLOCK AND CHRONOGRAPH—TOLLES'S MICROSCOPE OBJECTIVES—WALES'S—TILLMAN'S TONOMETER—HIS NEW CHEMICAL NOMENCLATURE.

COUNTRIES CHIEFLY REPRESENTED.

In the department embracing "instruments of precision and apparatus for instruction in science," the display presented by the Exposition, especially in the French and British sections, was very brilliant. The same was true, though less strikingly so, in the Prussian, Austrian, Belgian, Bavarian, Swiss, and Italian sections, and Russia also presented some instruments of great interest. The French exposition of this class of objects was truly magnificent, embracing probably a richer collection than any of its kind that was ever before brought together. Taken as a whole, it formed a happy illustration of the existing condition of experimental science, and exemplified strikingly the degree to which the recent progress of scientific discovery has been due to the achievements of art.

Splendid, however, and interesting as was this remarkable display, it contained few things with which the scientific world were not already familiar. Many instruments appeared under improved models; increased attention appeared to have been paid to the important object of combining the desirable qualities of lightness, strength, and rigidity; higher precision of indications had evidently been successfully sought; and examples of superior workmanship abounded on every side. Of apparatus designed to be auxiliary to investigation, there were specimens which might justly be called miracles of skill. Of instruments intended only for illustration or for demonstration there were others constructed upon a scale of dimensions truly grand. But of instruments or apparatus new in principle, or designed to conduct into novel fields of inquiry, the Exposition of 1867 was very nearly devoid. In static electricity, appeared here at a public Exposition for the first time the induction machine of Holtz; and in dynamic electricity, the somewhat analogous machine of Ladd. In acoustics, the visible resolution of complex sounds by means of tremulous

flames and revolving mirrors, which had not been exhibited in 1862, was first publicly presented. The application of the diapason to the measurement of minute intervals of time, for experiments in ballistics or in the experimental investigation of the laws of falling bodies, was also among the interesting things displayed in the Exposition of 1867, which had not been seen upon any former occasion of the same kind. But these and other similar evidences of progress in science, and improvements in the instrumental aids to observation or investigation, which figured prominently here, had become, for the most part, very generally known among men of science before the opening of the Exposition.

The notices which follow relate mainly to this class of objects. It would be unprofitable, and for the purposes of a report like the present, unsuitable, to attempt a description in detail of the apparatus exhibited, since, except for the peculiarities of secondary importance which distinguish one instrument from another of its kind, this would be but to re-write the known history of science. The space devoted to this branch of the present report will therefore be brief.

THE EXPOSITION OF THE UNITED STATES IN CLASS TWELVE.

It was impossible not to feel some regret in observing how imperfectly our own country was represented at the Exposition in this important department. We have not, it is true, a very numerous class of constructors of instruments of precision, and there has been little demand as yet among us for the highest grade of artistic skill in the construction of such instruments; but we have some establishments, which, if they had put forth their strength, might have enabled us to present a display which, even in presence of the highest achievements of European skill, could not have failed to do us honor. Americans asked, where are Ritchie, Green, McAllister, Würdemann, Zentmayer, Grunow, Chamberlain, Pike? Our countrymen could not but feel that, while we were nowhere adequately represented, in this department our representation was so disproportionately inadequate as to be likely to produce very unjust impressions abroad in regard to the state of science among us. Some things in the American department were, nevertheless, very creditable. The very superior balances sent by the office of weights and measures under the Coast Survey at Washington, attracted much attention. The impression produced by them upon the superintendent of the bureau of weights and measures of the Russian empire, who was one of the imperial commissioners at the Exposition, was so favorable, that he made a formal proposition to purchase the whole set for his government. They were not, of course, for sale; but a statement transmitted to Washington as to his wishes, resulted, it is believed, in securing the transmission to the government of Russia of a complete collection of the model weights and measures of the United States.

BARLOW'S PLANETARIUM.

The planetarium of Mr. Barlow, of Kentucky, was one of the attractions of the American section in this class. The beauty of the apparatus, the magnitude of the scale on which it is constructed, the ingenuity of its mechanism, the smoothness of the movements of its parts, and the variety of the phenomena which it illustrates, combined to secure for it universal admiration, and to keep it continually surrounded by curious groups.

BOND'S ASTRONOMICAL CLOCK AND CHRONOGRAPH.

The astronomical clock and chronograph of Bond were objects of still higher interest, and were also the most conspicuous among the objects in this class in the exposition of the United States, to which the term "instruments of precision" could be properly applied. They furnished one visible evidence, at least, to which we could point in proof of the existence among us of a very high order of mechanical skill.

TOLLES'S MICROSCOPE OBJECTIVES.

The objectives for microscopes, exhibited by Tolles, of Boston, and Wales, of New York, were, without doubt, equal to the best of their kind exhibited from any other country. It was to be regretted that these exhibitors did not accompany their glasses with the usual auxiliary apparatus, and especially with stands permitting the glasses to be tested; both because of the more satisfactory trials which they could thus have secured, and because of the beauty of the display which a properly arranged optical apparatus presents to the eye. Under the circumstances, there was some difficulty in getting these objectives properly before the jury; but their merits were ultimately recognized, and were very handsomely rewarded.

TILLMAN'S TONOMETER.

Among the contributions from our country which should have had a place in class twelve, were two by S. D. Tillman, esq., professor of technology in the American Institute, New York, which, by some unexplained error, were assigned to class thirteen, devoted to geography, cosmography, maps and globes. One of these was a device for illustrating visibly the theory of the musical scale and of musical temperament. This contrivance is called by its author a tonometer. Externally, it is a thin book of quarto form, having the general appearance of a geographical atlas, and to this fact the error of its classification was probably owing. This error prevented the notice of the object by the jury of either class. The jury of class thirteen passed it by, as not being within their province; and it did not come before the jury of class twelve at all. When it was at length discovered to have been neglected entirely, the juries had completed their labors, and had dispersed.

Owing to this accident, it seems to be but justice to the exhibitor to give some brief account here of his meritorious inventions. As to the

tonometer, before entering into a particular description of its construction, it will be necessary to premise a few observations relative to the subject which it is designed to illustrate.

Whatever may be the physiological causes which determine certain combinations of musical sounds to be more agreeable than others, the physical conditions which must exist in order to produce this effect are well known. Combinations of sounds are more pleasing in proportion as the vibrations which produce the separate notes are more frequently coincident in time. Next to the unison, which is only a reduplication of the same sound, the concord which is smoothest to the ear is that between the fundamental note, or tonic, and the octave; in which the numbers of vibrations performed in a given time are to each other as two to one. Other chords are formed of gradually decreasing smoothness by continual additions of a unit to each term of this ratio, so that the series of harmonic sounds within the octave will be expressed by the fractions—

$$\begin{array}{cccccc} \text{Unison.} & \text{Octave.} & \text{Fifth.} & \text{Fourth.} & \text{Major third.} & \text{Minor third.} \\ \frac{1}{1} & \frac{2}{1} & \frac{3}{2} & \frac{4}{3} & \frac{5}{4} & \frac{6}{5} \end{array} \quad \ldots\ldots \text{(I.)}$$

Beyond this point the series cannot be carried, the combination $\frac{7}{6}$ producing an effect unpleasing to the ear, or discordant.

The octave, its extremes excluded, embraces six notes. Intervals being named according to the number of notes of the diatonic scale which they embrace, including the extremes, the six notes form a series numbering from the second to the seventh. The series of simple ratios given above furnishes three of these only—the third, fourth, and fifth; the minor third above the tonic not being a diatonic interval. The sixth is implicitly given by the ratio $\frac{6}{5}$, since this note is a sixth below the octave but it is not necessary to deduce it in that manner.

By advancing the tonic successively to the several points in the scale represented by the simple ratios above, preserving still the numerical relations with the original fundamental note, and establishing upon each such newly chosen tonic the successive concords represented by the fractions in the series (I), other intervals will be obtained which will supply the three remaining notes of the scale. Thus:

$$1.\quad \begin{array}{ccccccccc} \text{Tonic.} & & \text{Fifth.} & & \text{Ninth.} & & \text{SECOND.} & & \\ \frac{3}{2} & \times & \frac{3}{2} & = & \frac{9}{4} & = & \frac{4\frac{1}{2}}{4} & = & \frac{9}{8} \end{array}$$

$$2.\quad \begin{array}{ccccccc} \text{Tonic.} & & \text{Fourth.} & & & & \text{Octave.} \\ \frac{3}{2} & \times & \frac{4}{3} & = & \frac{12}{6} & = & \frac{2}{1} \end{array}$$

$$3.\quad \begin{array}{ccccc} \text{Tonic.} & & \text{Third.} & & \text{SEVENTH.} \\ \frac{3}{2} & \times & \frac{5}{4} & = & \frac{15}{8} \end{array}$$

$$4.\quad \begin{array}{ccccccc} \text{Tonic.} & & \text{Minor third.} & & \text{Flat seventh.} & & \\ \frac{3}{2} & \times & \frac{6}{5} & = & \frac{18}{10} & = & \frac{9}{5} \end{array}$$

$$5.\quad \begin{array}{ccccccc} \text{Tonic.} & & \text{Third.} & & & & \text{SIXTH.} \\ \frac{4}{3} & \times & \frac{5}{4} & = & \frac{20}{12} & = & \frac{5}{3} \end{array}$$

$$6.\quad \begin{array}{ccccccc} \text{Tonic.} & & \text{Minor third.} & & & & \text{Minor sixth.} \\ \frac{4}{3} & \times & \frac{6}{5} & = & \frac{24}{15} & = & \frac{8}{5} \end{array}$$

$$7.\quad \begin{array}{ccccc} \text{Tonic.} & & \text{Minor third.} & & \text{Dissonance.} \\ \frac{6}{5} & \times & \frac{6}{5} & = & \frac{36}{25} \end{array}$$

The first of these derivatives is the interval of the second; the third the interval of the seventh; and the fifth the interval of the sixth. The diatonic scale is thus completed, and the places of its several notes are fixed by unalterable mathematical relations. Referred to the fundamental, they are—

Tonic.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.	
$\frac{1}{1}$	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{2}{1}$	......(II.)

The last is the repetition of the tonic, and the notes above repeat those of the original scale, doubling, quadrupling, &c., the numbers of vibrations. When the numbers of vibrations corresponding to these several notes are compared, not with the number belonging to the tonic, but each with the number immediately preceding, the intervals between the successive notes will be found to be the following:

Tonic.	Maj. tone.	Min. tone.	Semitone.	Maj. tone.	Min. tone.	Maj. tone.	Semitone.	
$\frac{1}{1}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	....(III.)

Reduced to a common denominator these fractions become—

Tonic.	Maj. tone.	Min. tone.	Semitone.	Maj. tone.	Min. tone.	Maj. tone.	Semitone.	
$\frac{360}{360}$	$\frac{405}{360}$	$\frac{400}{360}$	$\frac{384}{360}$	$\frac{405}{360}$	$\frac{400}{360}$	$\frac{405}{360}$	$\frac{384}{360}$	.(IV.)

The successive diatonic intervals are therefore of three different magnitudes, which are to each other as the numbers 45, 40, and 24; or as 9, 8, and 5, nearly. These latter numbers are commonly taken to represent them, although the last is a little too large. In this series 9 is the major tone, 8 is the minor tone, and 5 the semitone. The unit is the difference between the major and minor tones, and is called a comma. Hence we have—

For the entire octave, $9+8+5+9+8+9+5=53$ commas.

For the fifth, $9+8+5+9=31$ commas.

In point of fact, if the exact difference between the major and minor tones be taken as the unit, the number of commas in an octave, correctly estimated, is more than fifty-five and a half; but for ordinary uses, the values above given, as they are most convenient, are also sufficiently correct.

Since these inequalities exist between the successive intervals of a true diatonic scale, it follows that if the second or third, or any other note of the scale, be taken as the tonic note of a new scale, the notes of the new scale will not all of them correspond with those which follow in the same order in the primitive scale, and which approach nearest to them in pitch. This consideration, which is unimportant in the case of such musical instruments as admit of the indefinite variation of their tones, affects quite seriously the harmonies of one of which the scale is fixed and the number of notes of different pitch within the octave is limited. And an examination of the following table will show that an instrument in which, as in the piano, this number is no greater than twelve, must in many of its keys be very imperfect.

Numbers of vibrations corresponding to the true diatonic intervals in all the keys founded on the several notes of an original diatonic octave, having a fundamental note of 5,760 vibrations to the second.

	C.	D.	E.	F.	G.	A.	B.	C.	D.	E.	F.	G.	A.	B.	C.
Key of C	5,760	6,480	7,200	7,680	8,640	9,600	10,800	11,520	12,960	14,400	15,360	17,280	19,200	21,600	23,040
Key of D	*6,075	6,480	7,290	*8,100	8,640	9,720	10,800	*12,150	12,960	14,580	*16,200	17,280	19,440	21,600	*24,300
Key of E	*6,000	*6,750	7,200	*8,100	*9,000	9,600	10,800	*12,000	*13,500	14,400	*16,200	*18,000	19,200	21,600	*24,000
Key of F	5,760	6,400	7,200	7,680	8,640	9,600	†10,240	11,520	12,800	14,400	15,360	17,280	19,200	†20,480	23,040
Key of G	5,760	6,480	7,200	*8,100	8,640	9,720	10,800	11,520	12,960	14,400	*16,200	17,280	19,440	21,600	23,040
Key of A	*6,000	6,400	7,200	*8,000	*9,000	9,600	10,800	*12,000	12,800	14,400	*16,000	*18,000	19,200	21,600	*24,000
Key of B	*6,075	*6,750	7,200	*8,100	*9,000	*10,125	10,800	*12,150	*13,500	14,400	*16,200	*18,000	*20,250	21,600	*24,300
Key of C	5,760	6,480	7,200	7,680	8,640	9,600	10,800	11,520	12,960	14,400	15,360	17,280	19,200	21,600	23,040

* The notes marked with a star, are those in which the black finger-key next above the white one corresponding to the letter is taken in instruments which have but twelve finger-keys to the octave.

† For this note the black finger-key next below the white one corresponding to the letter must be taken in the same class of instruments.

Besides these large differences there are others of less magnitude, which must be tolerated or measurably corrected by temperament, thus: D is 6,400, and 6,480; E 7,200, and 7,290; A 9,600, and 9,720. Between the starred notes similar differences appear.

In order to avoid fractions, the number of vibrations of every note is referred to that of a fundamental tonic assumed at 5760 to the second, and only the keys corresponding to the natural notes of the diatonic scale are given. If the keys deduced from all the notes of the chromatic scale were added, the diversities would be much more numerous. The numbers included between the heavy lines passing diagonally through the table, are those of the complete octave in the successive scales. The other numbers are added for the purpose of comparison. It will be seen that in the key of D there are four notes which differ from those approximating the same pitch in the primitive scale, and that D has itself, in the different series, the three different values 6480, 6400, and 6750. In the key of B, all the notes but two differ from those in the original key of C.

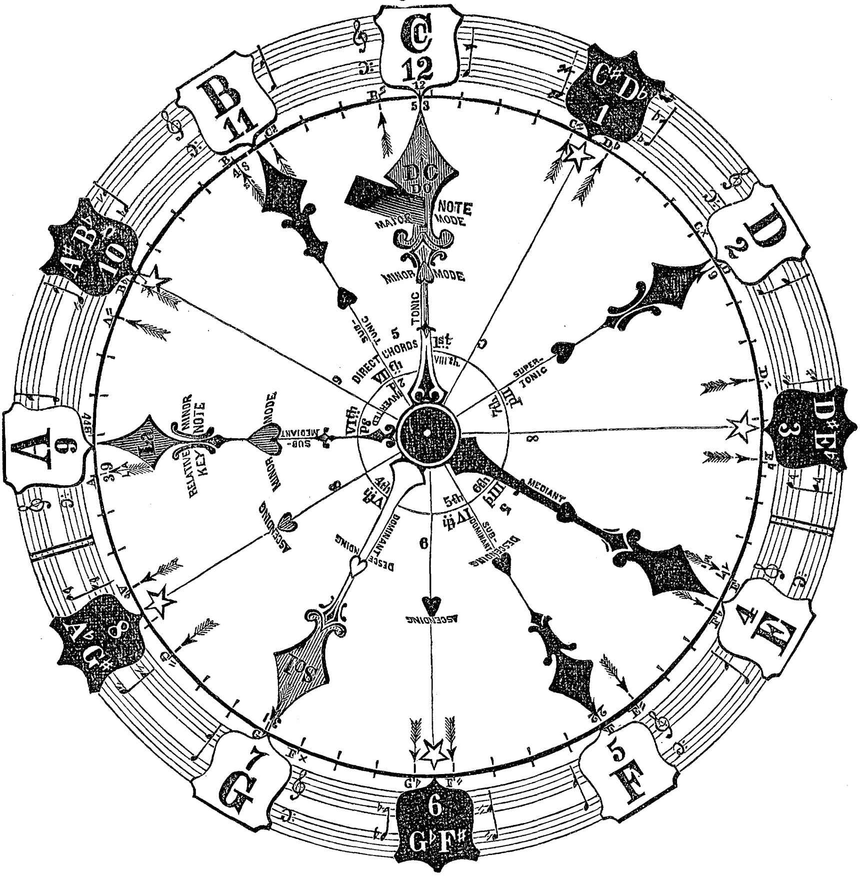
If all the tones were equal, and if the semitone were half a tone, as its name implies, these discrepancies would not occur. The octave would consist of twelve equal semitones, and a twelve-keyed instrument would be equally perfect on every scale. In order to reduce the complication of instruments, the expedient naturally suggests itself to introduce such an equality, by altering the notes to some slight extent, so that while the instrument is quite perfect upon none of its scales, it shall be equally imperfect upon all. Such a temperament requires but five finger-keys to be added to the seven which form the diatonic octave, and makes each key interposed between every two full tones equally serviceable for the flat of the note above and the sharp of the note below. In point of fact such flats and sharps differ from each other by one or two commas, and the natural semitones never coincide with those of the chromatic scale. The temperament here proposed is not agreeable, and the method actually practiced is to modify the notes in such a manner as to keep nearest to the truth in the most frequently recurring scales.

Another reason for the necessity of temperament of some sort arises out of the incommensurability of the simple numbers *two* and *three*, and their powers; so that in passing through a series of fifths or fourths, in modulating from key to key, an exact transition is impossible. Taking the value of the octave at fifty-three commas, and that of the fifth at thirty-one commas, seven octaves will amount to three hundred and seventy-one commas, and twelve-fifths to three hundred and seventy-two commas; whereas, if the fifth were seven-twelfths of the octave, as in equal temperament it would be, twelve-fifths should be precisely equal to seven octaves. If the exact difference between the major and minor tones, viz., $\frac{81}{80}$, be taken as the value of the comma, the value of twelve-fifths will be 391.67, and that of seven octaves 390.58; the difference being 1.09, or about a comma and a tenth.

Of all this subject, which is so little understood by most persons who make use of musical instruments, Prof. Tillman's Tonometer furnishes a simple elucidation, which, by directly addressing itself to the eye, conveys the truths to be illustrated more directly and more clearly than

pages of numerical statements can do. A circle represents the octave, (the *septave* Prof. Tillman calls it, taking the name from the number of intervals rather than from the number of notes required to produce them.) This is divided into twelve equal semitones, or *grades*, as he names them,

Fig. 94.



Tillman's Tonometer Dial.

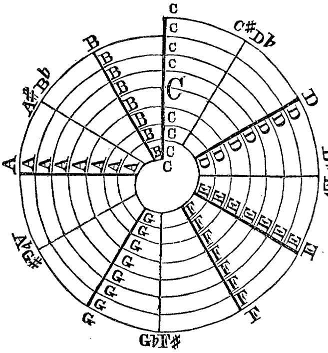
each containing five artificial commas, making sixty in all. Seven white escutcheons mark the places of the notes of the natural diatonic scale; and five black escutcheons indicate the interpolated semitones. Two circular musical staves connecting these escutcheons show the places of the several notes as written in the tenor and in the bass. The C, as the tonic note of the natural scale, takes its place at the top of the circle. The other letters follow in their order. But while the system of equal temperament is shown by the twelve visible grades, the proper places of the notes of the chromatic scales are shown on the circular division with proper marks. This is the fixed part of the apparatus.

Within the circle just described is a movable circle revolving on the common center, and carrying seven conspicuous arms, each terminated

by a spearhead, which point to the several notes of the natural diatonic scale as determined by equal temperament, when the leading arm is brought opposite to the origin at C. If the same leading arm is brought opposite to any other letter or escutcheon, the remaining arms point out in like manner the notes of the corresponding scale, and indicate such as are affected by sharps or flats. Five less conspicuous arms, ending each in a star, divide equally the spaces which, in the first system, represent the full tones.

So far, the instrument is useful in illustrating the construction of the different scales, and in teaching modulation. But the circumference of the revolving circle is divided into fifty-three commas instead of sixty, and it shows, by means of arrows directed to the proper divisions, the places of the true or untempered notes in every scale; and exhibits therefore at a glance the degree to which the system of equal temperament does violence to the natural relations of the notes to each other. And thus it furnishes the means of studying the effect of any temperament, and of easily comparing one system with another. As an aid to the musical education of such students as do not desire to be profound, its usefulness cannot but be very great; since, with little effort on the part of the learner, it conveys definite ideas upon a subject respecting which very many form no clear notions at all.

Fig. 95.



Prof. Tillman has an ingenious mode of representing pitch, and illustrating the recurrence of musical sounds in a succession of octaves, by means of a spiral in which the radius vector is the index of the pitch, and a series of fixed radii mark the places of the notes in the diatonic scale in every octave. The law of this spiral will be expressed by the equation

$$dr = a d\varphi,$$

supposing r to be the radius vector, and φ the angle described from the origin. If $r=1$ when $\varphi = 0^\circ$, and $r=2$ when $\varphi = 2\pi$, the value of a will be $\frac{1}{2\pi}$. In order, then, to connect the length of the radius vector with the numbers of vibrations corresponding to its different positions and lengths, we must suppose the revolution to begin when $r=1$, and assume the initial number of vibrations per second $= n$. Put also the number at any subsequent point $=$ N. Then the number of revolutions, integral or fractional, which may be put $= \nu$ will be $= r - 1$.

$$\text{And } \nu = r - 1 = \frac{\varphi}{2\pi}. \quad \text{Also } \mathrm{N} = n2\nu = n2r^1.$$

Whence: $\operatorname{Log} \mathrm{N} = \operatorname{Log} n + (r-1) \log 2.$

$$\text{And } r = \frac{\operatorname{Log} \mathrm{N} - \log n + \log 2.}{\log 2}$$

If we put $N = 6502$, and $n = 512$, we shall obtain $r = 4.67 = 4\frac{2}{3}$. And $\nu = r - 1 = 3.67$, showing that the radius belongs to the fourth turn of the spiral at 240° from the origin.

Prof. Tillman's tonometer is accompanied by a concise treatise on the general principles of music, including harmony and modulation, which this instrument serves very happily to illustrate.

TILLMAN'S PROPOSED CHEMICAL NOMENCLATURE.

The other part of the contribution of Prof. Tillman to the Exposition consisted in a project for a new chemical nomenclature, designed to remove the disadvantages attending the existing cumbrous system, which, with the progress of the science, especially in the organic department, is becoming daily more embarrassing. While it is peculiarly adapted to the typical mode of classification which is continually gaining ground and is likely to become universal, it accommodates itself equally to the older form, and is suited to be of the greatest utility, considered merely as a system of mnemonics, to those who prefer to use it simply as an auxiliary to forms with which they are already familiar. The advantages of the scheme are briefly—

1. It provides for every known or possible combination a distinct significant name, expressing briefly, and usually in a single word, all the elements which enter into the compound, with the proportions in which they enter.

2. It enables any one to give at once to any new or supposed compound, a name which shall be immediately intelligible to every other person; and makes it equally possible also to understand the nature of any compound named by another.

3. It simplifies exceedingly the machinery of thought, assisting the chemist in this respect very much as the mathematician is aided by the symbols of algebra and arithmetic.

The principles according to which this nomenclature is constructed, are concisely stated by the author as follows:

"1. The system is based on abbreviations of the universally received names of the metals, and on the chemical symbols of the metalloids or non-metallic elements, with such modifications as were imperatively required.

"2. The name of each chemical element relates, not to its mass, but only to a minimum combining proportion termed an atom, or to some multiple of it. The atom is therefore the unit of measurement, and the starting point of the scale in each series of compounds.

"3. The atomic name of each metal consists of two syllables, and ends with the consonant *m*.

"4. The name of each of the thirteen metalloids terminates with a different consonant. Arsenic and tellurium, classed by French chemists among the metalloids, have in this arrangement the terminal letter common to the metals.

"5. The number of atoms of any element is designated by the vowel immediately preceding its terminal consonant. The numerical power of the vowels advances with the order in which they are placed in the alphabet. *One*, *two*, *three*, *four*, and *five* are respectively expressed by *a*, *e*, *i*, *o* and *u*, having the short or stopped sound as heard in *bat*, *bet*, *bit*, *hot*, *hut;* and *six*, *seven*, *eight*, *nine* and *ten* by the same vowels having a long or full sound. In foreign languages, it may be best to designate the long sound by a sign placed *over* the vowel; but in our language, it is found by experience more convenient to place *e before* each of the vowels, which invariably indicates their long or full sound as heard in the words *great*, *greet*, *sleight*, *yeoman*, *euphony*. These ten distinctive sounds may be illustrated by a single example. From one to ten atoms of iron, inclusive, have the following names:

Fe, *Ferram ;* Fe_2, *Ferrem ;* Fe_3, *Ferrim ;* Fe_4, *Ferrom ;* Fe_5, *Ferrum ;* Fe_6, *Ferream ;* Fe_7, *Ferreem :* Fe_8, *Ferreim ;* Fe_9, *Ferreom ;* Fe_{10}, *Ferreum.*

The proper diphthongs are sometimes used for the even numbers between 10 and 20. These will be remembered from the fact that their value is the sum of their vowel-values, either short or long: thus, *oi* is $12 = 9 + 3$; *ou* is $14 = 9 + 5$; *au* is $16 = 6 + 10$; *oo* is $18 = 9 + 9$. The consonant *y* is 10, and used only in connection with vowels, which will express all the numbers to and including 20; *w* is 20, and, with the usual appendages, will express the numbers to and including 30. *X* is also used, and when *preceded* by a vowel, which thus has the power of an exponent, will express a progression by tens to one hundred; thus 10, *ax ;* 20, *ex ;* 30, *ix ;* 40, *ox ;* 50, *ux ;* 60, *eax ;* 70, *eex ;* 80, *eix ;* 90, *eox ;* 100, *eux.* In the same manner these vowels preceding *qu* express the hundreds to and including one thousand, and the intermediate numbers are represented by suffixing some of the characters previously explained.

"Very few chemical compounds, now known, have a composition represented by atomic numbers higher than one hundred. A large majority of the bodies of known composition do not require numbers as high as ten. The following selections will show more clearly the numerical value of each letter, and the extent to which this numerative system may be carried:

a, 1	*ea*, 6	*aa*, 11	*y*, 10	*w*, 20	*ax*, 10	*aqu*, 100
e, 2	*ee*, 7	*oi*, 12	*ya*, 11	*wi*, 23	*ex*, 20	*equ*, 200
i, 3	*ei*, 8	*ou*, 14	*yi*, 13	*wee*, 27	*ix*, 30	*eiqu*, 800
o, 4	*eo*, 9	*au*, 16	*yeo*, 19	*weo*, 29	*eix*, 80	*eoquix*, 930
u, 5	*eu*, 10	*oo*, 18	*yeu*, 20	*weu*, 30	*eux*, 100	*euqueix*, 1080

"6. The following metalloids have names terminating with their well-known symbolic letters; one atom of each is here denoted:

Fluorine,	*fluraf* or *af;*	Bromine,	*bromab* or *ab ;*
Nitrogen,[1]	*nitran* or *an;*	Phosphorus,	*phosap* or *ap ;*
Carbon,	*carbac* or *ac;*	Sulphur,	*sulphas* or *as.*

[1] In the French, *Azan.*

"In a few instances where the symbolic letter could not be used, the terminal letter adopted may be associated with some prominent characteristic of the element. Thus *l* represents the *lightest* of substance, an atom of hydrogen is *hydral* or *al;* *d* represents the *densest* of the gaseous elements, an atom of chlorine is *chlorad* or *ad;* *v* represents a *volatile* producing a *violet* vapor, one atom of iodine is *idav* or *av.* The atom *par excellence* is *at;* oxygen, exceeding in quantity all other elements of the earth's crust, has for the name of a single atom *oxat* or *at.* An atom of selenium is *selaz* or *az;* it bears a strong resemblance in its reactions to *as.* Boron and silicon or silicium, like carbon, are permanent solids when isolated; their terminals may be remembered by the association of *j* and *k* in the alphabet; an atom or boron is *boraj* or *aj*, an atom of silicon is *silak* or *ak.*

"The compounds of carbon and hydrogen are so numerous that it has been found essential to provide an additional character to represent each. The letter *r* may be associated with the radiating and refracting power of carbon; and *carbar* or *ar*, as well as *ac*, will represent an atom of carbon. As *ac* might be mistaken for *ak*, in radical compounds, the carbon component is denoted generally by *r.*

"The only case in which it has been found advantageous to use one letter to designate two atoms, is that of *h* for two atoms of hydrogen, or *hydrel;* thus preserving the ratio of the old combining numbers, $C_2H_2O_2$ being *cht.* It will be noted that *ach* corresponds with C_2H_2 in the old notation, and with CH_2 in the new: it is the key to a series of radicals, *i. e.*, methyl, CH_3, is *achal;* ethyl, C_2H_5, *echal.*

"7. Metalloid terminal syllables express as much as the full name, and are used as suffixes to names of metallic atoms to denote a metallic compound; for example, the protoxide of iron is *ferramat*, which indicates very clearly that one atom of iron is united with one atom of oxygen. A combination of metalloid syllables represents a non-metallic compound. In numerous cases, the number of syllables forming such a word is less than the number of different elements in the compound, because two or more terminal characters may be united, and the vowel or diphthong preceding the whole will be applicable to each; for instance, *elt* = H_2O_2 is a molecule of oxygenated water, or peroxide of hydrogen; *arn* = CN is an atom[1] of cyanogen, and *ant* = NO is a molecule of binoxide of nitrogen. It will be seen presently that the names of salts containing one atom of a metal are sometimes slightly abbreviated, by omitting the *a* which should precede *m;* also that *m*, with a vowel preceding it, is applied to multiples of any radical playing the part of a metal."

These principles are applied in an essay extending to twenty or thirty pages, in which the application is pursued into every branch of the subject, and the adaptability of the system to every variety of theoretic view is illustrated by examples. The following instances serve to show the extent to which it carries abbreviation in some of the compounds produced by substitution in organic chemistry:

[1] Atomoid?

Chlorides and bromides of naphthaline, with Gmelin's names and formulæ.

Gmelin's names.	Gmelin's formulæ.	New names.
Hydrochlorate of chlorobromonaphthaline	$C_{10}H_6BrCl\ HCl$	= *eureelabed.*
Hydrobromate of quadribromonaphthaline..........	$C_{10}H_4Br_4\ HBr$	= *eurulb.*
Bihydrochlorate of bichloronaphthaline	$C_{10}H_6Cl_2\ 2\ HCl$.....	= *eureilod.*
Bihydrochlorate of bromochloronapthaline..........	$C_{10}H_6BrCl\ 2\ HCl$ ...	= *eureilabid.*
Bihydrochlorate of bibromobichloronaphthaline	$C_{10}H_4Br_2Cl_2\ 2\ HCl$..	= *eurealebod.*
Bihydrobromate of bibromobichloronaphthaline	$C_{10}H_4Br_2Cl_2\ 2\ HBr$..	= *eurealedob.*
Bihydrobromate of terbromochloronaphthaline	$C_{10}H_4Br_3Cl\ 2\ HBr$...	= *eurealadub.*
Bihydrobromate of quadribromonaphthaline	$C_{10}H_4Br_4\ 2\ HBr$	= *eurealb.*
Bihydrochlorate of bibromoterchloronaphthaline.....	$C_{10}H_3Br_2Cl_3\ 2\ HCl$..	= *eurulebod.*

This nomenclature would be worthy of attention, if it were only on account of the remarkable abbreviation which it introduces into the language of the science; but the author claims for it, justly, a greater advantage in the fact of its comprehensive significancy. This idea is expressed in the remark that "he who knows why he calls chloroform *arlid*, knows on the instant, and knows for life, that it is composed of one of carbon, one of hydrogen, and three atoms of chlorine; or when he designates laughing gas by *genat*, he announces at once several facts not indicated by the old names, nitrous oxide or protoxide of nitrogen."

CHAPTER XVI.

PHYSICS.

GRAVITY—DENSIMETERS—BALANCES—LAWS OF GRAVITY—PNEUMATICS—GEISSLER'S AIR-PUMP WITHOUT VALVES—KRAVOGL'S MERCURIAL AIR-PUMP—RICHARD'S MULTIPLE EXHAUSTION—DELEUIL'S—SOUND—KŒNIG'S EXPOSITION—SIRENS—RESONATORS—SCHEIBLER'S TONOMETER—GRAPHIC METHODS IN ACOUSTICS—OPTICAL METHODS—MECHANICAL AND OPTICAL METHODS COMBINED—SONOROUS FLAMES—HEAT—THERMOMETERS—PYROMETERS—LIGHT—OPTICAL GLASS—TÖPLER'S STRIÆ DETECTOR--POLARIZATION APPARATUS--PHOSPHORESCENCE--SPECTROSCOPES--RUTHERFURD'S SOLAR SPECTRUM—TELESCOPES—MICROSCOPES—STATIC ELECTRICITY—ELECTRO-STATIC INDUCTION MACHINES—VARLEY'S--TÖPLER'S—HOLTZ'S—BERTSCH'S—DYNAMIC ELECTRICITY—BATTERIES—EBNER'S—FARMER'S—SECCHI'S—CALLAUD'S—MINOTTO'S—MARIE-DAVY'S—LECLANCHÉ'S—BUNSEN'S BICHROMATE BATTERY—THOMSEN'S POLARIZATION BATTERY—THERMO-ELECTRIC BATTERIES—FARMER'S—MARCUS'S—BECQUEREL'S—ELECTRO-MAGNETS--INDUCTION COILS—GEISSLER'S TUBES—DE LA RIVE'S AURORA APPARATUS—METEOROLOGY—AUTOMATIC METEOROLOGICAL REGISTERS—SECCHI'S METEOROGRAPH.

I.—GRAVITY.

Instruments which are employed to determine the densities of liquids, the weight of masses of matter in any form, the absolute force of gravity at different elevations or in different latitudes, or finally, the laws which govern the motion of bodies falling freely under the influence of gravity, or acted upon by gravity jointly with other forces, including their own inertia, may all be properly considered under the general title placed at the head of this section.

DENSIMETERS.

The nomenclature of instruments designed to ascertain densities by direct observation has been quite unnecessarily extended. Besides the terms *hydrometer*, *areometer*, and *volumeter*, which are generally familiar and have relation to the physical properties of matter in the liquid state, we have also, *alcoömeters*, *lactimeters*, *saccharimeters*, *alkalimeters*, and many others, denoting the special objects for which the instruments so named are intended. It is greatly to be desired that this confusion of terms and consequent multiplication of the forms of an instrument which, under all its varieties, fulfills only one and the same function always, viz: that of determining the specific gravity of a liquid in which it is plunged, should be done away with. A densimeter does not indi-

cate the quantity or proportion of alcohol, or sugar, or alkali, in a solution. It indicates only the weight of a unit of bulk of the solution as compared with that of an equal bulk of water. The proportion of alcohol, salt, &c., which corresponds to this specific gravity, may be found from tables in which have been arranged the results of carefully conducted experiments on mixtures. With the help of such tables, the same densimeter may be used for all the varieties of purpose for which many constructors now provide independent instruments. There could of course be no objection to providing a densimeter with a double scale, having one graduation for general densimetrical purposes, and another for alcoömetry, saccharimetry, &c., as the case may be; but the second scale, without the first, limits the use of the instrument to one special object. Hence, it was one of the recommendations of the international congress assembled in Paris, during the continuance of the Exposition, to deliberate on the unification of weights, measures, and coins, that all densimeters should hereafter be constructed to indicate specific gravities, as referred to water taken at its maximum density.

Among the densimeters on exhibition in the Exposition, there were noticed no novelties of special interest. These instruments were for the most part constructed of glass; but in the Russian section, Mr. L. Andree, of Riga, presented some elegantly finished models in aluminium bronze. The material of which a densimeter should be constructed, is a question upon which opinions are divided. It is objected to metal, that its malleability and flexibility make it liable to change of form by accident or by fraudulent design. But such are the extreme hardness and rigidity of aluminium bronze, that the objection here suggested, so far as this metal is concerned, is rather more imaginary than real. It is, however, a more serious objection that the size of a densimeter of metal may be skillfully reduced by a file or scraper, the injured parts being subsequently repolished, or gilded over in case the instrument had been originally gilded. Against the possibility of this description of fraud, however, is to be offset the absolutely certain detection which follows, when the instrument is carefully weighed in the air. Glass, on the other hand, cannot change its figure by percussion or compression, nor can it be reduced in size by abrasion without the destruction of a polish which cannot be easily renewed. The bulb of a glass hydrometer might be varied in size under the glass-blower's blow-pipe; but supposing it to have been originally silvered on the interior, or coated with any varnish permanent at ordinary temperatures, this kind of fraud could not be successfully practiced. But the fragility of glass hydrometers is a great disadvantage, and in the public service is the occasion of frequent inconvenience. Horn-rubber, or ebonite, would seem to combine the qualities most desirable in an instrument of this description. This material has been proposed by the present reporter, and perhaps by others, for the uses of the United States revenue service; but for reasons not fully understood, or so far as understood by no means satisfactory, construc-

tors have been unwilling to adopt it. The belief is, nevertheless, confidently entertained that this material will ultimately be found, for ordinary densimetric purposes, preferable to any other.

BALANCES.

The balances shown in the Exposition, which were numerous and in many instances elegant, were distinguished rather for excellence of workmanship, and for the delicacy of their indications, than for originality in regard to construction. In this latter respect, the only real novelty noticeable consisted in the "arc of precision" invented a few years since by Gallois, and recently adopted by some of the best known constructors of France, Belgium, and Germany. This is an expedient for making delicate determinations of fractional weights, by deflecting more or less to the right or left an index needle attached to the beam of the balance beneath the center of gravity. When this index points directly downward, like the ordinary fixed needle of the balance, its effect upon the equilibrium of the balance is of course zero. When deflected so as to form an oblique angle with the horizontal axis of the beam, it contributes a portion of its weight, dependent on the amount of deflection, to the side toward which it is inclined. When, in the process of weighing, a position of the needle has been found which produces equilibrium, the fractional weight contributed by the needle is read upon a circular arc, which is situated immediately behind it, and is suitably divided. The division, of course, must be made experimentally at the time of the construction of the balance.

Hitherto the most popular expedient for ascertaining these slight differences has been the divided scale beam and the riding weight. The riding weight is a twisted wire of platinum or gold, hardly larger in diameter than a hair, which is picked up and transported from point to point on the balance beam, by means of a sliding-rod passing through the side of the case and operated from without. This contrivance is less simple than that of Gallois, and requires some dexterity to manage it well. Which of the two affords practically the best results remains to be settled by experience.

Very fine balances, furnished with the arc of precision, were exhibited by Messrs. Sacré, of Brussels, J. and L. Reiman, of Berlin, and Hempel and Collot, of Paris, who also presented balances of the ordinary construction.

The sensibility of the balances exhibited may be judged of from the following examples, in which the load in each scale is expressed in grams and the turning weight in milligrams, or fractions of a milligram:

Constructor.	Load in each scale.	Turning weight.	Ratio turning weight to load.
Hempel, Paris	30	0.05	1:600,000
Hagershoff, Leipzig	100	0.2	1:500,000
Sauter, Elbingen	100	0.1	1:1,000,000
Kravogl, Innsbruck	100	0.1	1:1,000,000
Collot, Paris	250	0.5	1:500,000
L. Reiman, Berlin	500	0.2	1:2,500,000
J. Reiman, Berlin	1,000	1.0	1:1,000,000
Horn, Berlin	1,000	0.1	1:10,000,000
Rohrbeck, Berlin	1,000	0.5	1:2,000,000
Saxton, United States	1,000	0.2	1:5,000,000
Hempel, Paris	2,000	0.5	1:4,000,000
Collot, Paris	2,000	1.0	1:2,000,000
Sacré, Brussels	5,000	0.5	1:10,000,000
Hagershoff, Leipzig	5,000	5.0	1:1,000,000
Deleuil, Paris	5,000	0.5	1:10,000,000
Saxton, United States	20,000	1.0	1:20,000,000
Collot, Paris	35,000	5.0	1:7,000,000

The large balance of Collot was the most remarkable object of its kind exhibited by any European constructor. The beam was of fifteen kilograms weight, and rested on knife-edges of steel supported by plane surfaces of agate. The long index needle was constructed of aluminium, in order to diminish its weight, and the whole apparatus was sustained upon a base of cast iron, which, for the purpose of securing stability and neutralizing tremors, was made of the great weight of nine hundred kilograms, (nearly a ton.) This balance being intended for the verification of the larger measures of capacity, is provided with auxiliary apparatus to facilitate loading and unloading. A small car, running on a railway, receives the charge and conveys it up to the scale, when, by means of a kind of derrick, it is transferred to the platform without shock or jar, and without requiring the operator to touch it with his hand.

The large balance exhibited by the Bureau of Weights and Measures of the United States Treasury Department, also attracted much notice from its simplicity, strength, judicious proportions, and excellent workmanship. The smaller balances exhibited along with this were also much admired. By some accident these balances did not appear in the catalogue of the Exposition. They were, therefore, overlooked by the jury of the class to which they belonged; a circumstance of less importance, as they would probably have been pronounced *hors concours*. In the year 1851, balances identical in construction with those exhibited in 1867 were presented by the government of the United States to that of France, as a part of a set of the standard weights and measures of our country, sent in exchange for a similar set of the French weights and measures previously received. The judgment of Mr. J. C. Silbermann, at that time superintendent of the collections of the *Conservatoire des Arts et Métiers*, and then the highest authority in France in this branch

of applied science, in regard to the merit of these balances, was expressed in a letter to Mr. Alexander Vattemare, agent of international exchanges, under date of March 6, 1852, and was so emphatic and so complimentary that the reporter may be pardoned for reproducing it here. Mr. Silbermann says:

"In the first place I will communicate to you the opinion of connoisseurs, and I beg of you to believe that each instrument has been well examined and well appreciated. This opinion is, that all these articles are of irreproachable execution; the two balances particularly are the objects of universal admiration. Public opinion cannot go further. In testimony of the esteem in which I hold these balances, I cannot say more than that I used the small one to adjust the platinum kilogram, which was exhibited at the World's Fair, in London; it is very delicate and especially most constant. I was able to make all my weighings with certainty to within half a milligram. The form adopted for these balances is at once simple, well adapted to use, and distinguished by that taste which is only to be found in instruments made by master hands. These are justly to be termed instruments of precision.

"What I have just said with regard to the small balance, I may repeat with still more propriety respecting the large one: it is not inferior to the former in precision. In fact I have tested it with ten kilograms in each scale, and it promptly indicates a difference of one-half a milligram between the two weights; that is to say, one unit in twenty millions in each scale. I have been obliged several times to repeat this experiment in presence of incredulous persons, and it has always given the same result. What is most gratifying to me in the construction of these balances, is the system adopted in the United States, which consists in preventing the oscillation of the balance, and causing it to tilt as soon as the equilibrium is destroyed; the weighings are effected very rapidly, and, as it has been seen, with as much precision as can be obtained with the most carefully made balances. For my part, I have ever regretted that all our balance-makers have hitherto declined the adoption of this system. They assign, as the reason of this reluctance, that, with an oscillating balance, they can replace the small weights by arcs of oscillation, which enables them to estimate much smaller fractions of the milligram. As for myself, I am inclined to believe that as much precision may be arrived at in one system as in the other; and in that case there will be a great gain of time in the system of tilting. Moreover, I know from experience what confidence is to be placed in weights estimated by arcs; in spite of the utmost care, the above-mentioned very small arcs are variable; and, while they flatter us with the hope that we have obtained tenths of a milligram, they cause us to commit, unwittingly, errors of more than one or two milligrams."

The good opinion of these balances thus expressed fifteen years ago by Mr. Silbermann continues to be entertained of them by his able and efficient successor, Mr. Tresca. This gentleman, on whom it devolves

to make all the comparisons of standard weights and measures furnished by the imperial government to the provinces or to foreign countries, stated to the present reporter that in the comparison of heavy weights he always used the large American balance in preference to any other.

Before leaving the subject of balances, mention should be made of the alarm balances, or automatic hammer balances, as they are called by the exhibitor, Mr. Deleuil, which appeared in the French section. One of the forms of the instrument so named was originally constructed for the municipal service of Paris, to be employed in testing the illuminating power of the gas furnished for lighting the streets. The standard light employed in the process of testing is an oil lamp regulated to a uniform consumption. The gas is burned in a porcelain burner. As for the photometer, its construction is quite simple. In the metal base of a hollow cone are introduced two disks of ground glass, on one of which falls the light of the lamp, and on the other that of the gas jet. The experiment is conducted, as a matter of course, in a dark room; and the observer placing his eye at the truncated summit of the cone, causes the flow of gas to be regulated until the two disks appear of equal brightness. The lamp is accurately equipoised upon the scale of the alarm balance, and then a certain number of grams is removed from the counterbalancing scale. As the oil is consumed the lamp gradually loses weight, till at length the scale beam tilts in the opposite direction. This tilting causes the fall of a light hammer which is attached in a vertical position, with the hammer head uppermost, to the index needle of the balance, and which is prevented by a stop from falling toward the lamp, though it is free to fall in the opposite direction so soon as the needle passes the vertical. The hammer falling upon a bell gives notice to cut off the gas. Then by a comparison of the consumption of gas indicated by the meter with the known weight of oil consumed, the inference as to the quality of the gas is easily deduced.

The same principle has been applied by Mr. Deleuil to the determination of the exact amount of gold or silver deposited in the process of galvanic plating and gilding. In this case the objects receiving the deposit determine the tilting of the balance when their weight has been increased by the amount desired; and as this point may be reached in the absence of attendance, the movement is made to arrest the operation by breaking the electric circuit.

LAWS OF GRAVITY—ACCELERATION OF FALLING BODIES.

The velocities acquired by bodies falling freely under the influence of gravity are so great as to render the investigation of the law of acceleration by direct observation extremely difficult. On the one hand, if the spaces fallen through are small, the duration of the experiment is too brief to furnish satisfactory results. The minutest error in assigning the exact instant of commencement or end of the fall will seriously affect the value of the observation. On the other hand it is difficult to

find situations in which bodies can be observed in their descent from great heights; and even supposing this difficulty less, the observations on such falls would be vitiated and rendered practically useless by the great resistance opposed by the atmosphere to all bodies moving with high velocities.

The most satisfactory instrumental means of visibly illustrating the laws of falling bodies has hitherto been found in the machine invented about a century ago by George Atwood, which is familiarly known in every physical lecture-room under the name of Atwood's machine. In this machine, a light wheel, delicately supported upon large friction wheels, carries two equal weights by means of a small and very flexible silken cord which runs in a groove upon its circumference. This wheel, with its supporting apparatus, is placed upon the top of a frame seven or eight feet in height; and motion is given to the system of suspended and equipoised weights by placing upon one of the two a small additional weight, bearing a definite proportion to the whole equipoised mass. The moving force is this additional weight; the mass moved will be many times this weight, and the velocity generated in a given time will be just as many times less than that which gravity would produce in a body freely falling for the same time. Thus, if the whole mass moved is sixty-four times as heavy as the added weight which furnishes the motive power, the velocity generated in one second will be one sixty-fourth of that produced in one second by free gravitation. And as that is known to be thirty-two feet (with a fraction which may for the present purpose be disregarded,) the velocity acquired in the experiment, under the circumstances supposed, will be thirty-two feet divided by sixty-four; that is to say, six inches. And as the space fallen through in the first second is only one-half as great as that which expresses the acquired velocity, the weights in the machine will only move through a space of three inches from rest in this first second in the experiment supposed. With a motion so deliberate it is possible to illustrate fairly the laws which govern the movements of bodies subjected to the action of constant forces. Yet there is still so much of inevitable inexactness in marking the instants limiting an observation, that the machine of Atwood, though extremely interesting and really serviceable for purposes of instruction, is hardly entitled to be called an instrument of precision.

Another machine, designed by General Morin, for a purpose similar to that had in view by Atwood, has been received by physicists as a useful addition to their means of instrumental illustration. The essential part of this machine is a vertical cylinder, six or seven feet high, turning easily upon its axis of figure, and driven by clock work and a descending weight. A wind-vane regulator serves to maintain uniformity of rotation. The cylinder is closely wrapped with white paper, which ought to be ruled with equidistant parallel lines, both horizontally and vertically. A weight which is perfectly free to fall when released from

a detent at the top of the machine, is guided in its fall by a couple of wires stretched vertically, and carries in its descent a pencil of which the point is kept by a light spring in contact with the paper wrapping the revolving cylinder. At a given instant the detent is touched and the weight falls. The velocity of descent is accelerated, while that of rotation is uniform. The curve described by the pencil as the combined result of these two motions will be found, by measuring its co-ordinates on the paper, to be a parabola; and from this may be deduced the law regulating the fall.

Another mode of deducing this law from observation was suggested, nearly thirty years ago, by Professor Wheatstone, in which the difficulty of noting the moments of commencement and end of the fall is overcome by calling in the aid of electricity. The rupture of an electric current drops the weight, and starts a chronoscope at the same instant; the impact of the body at the end of the fall suddenly arrests the chronoscope and records the interval of time elapsed. By increasing or diminishing the distance fallen through, the relations are ascertained of space to time.

In the present Exposition, an instrument is exhibited by Mr. Bourbouze, of Paris, which, for the accuracy of its indications, seems to offer some important advantages over all the methods heretofore employed for illustrating the laws of falling bodies. Like Atwood's machine, the contrivance of Mr. Bourbouze has a pulley mounted on friction wheels, which carries upon the same axis a very light cylinder. The pulley also, as in the machine of Atwood, sustains two equipoised weights, and is put in motion by placing on one of these an additional weight. The cylinder above mentioned is covered with paper which is coated with lampblack from the smoke of burning turpentine. Opposite the cylinder is placed a diapason, one of the arms of which carries a tracer which touches lightly the smoked surface of the cylinder. The vibration of this diapason, after being mechanically excited, is maintained by the attraction of an electro-magnet, of which the circuit is alternately closed and broken by the vibration itself. The time of the vibration is known by the pitch of the resulting sound. Supposing that, during the vibration, the cylinder is put into rotation with a uniform velocity, the tracer will describe a sinuous mark in which the summits of the successive undulations will be equidistant. But if the velocity of rotation is accelerated, these successive intervals will be larger and larger, though still denoting equal intervals of time; so that by a comparison of their lengths the law of velocity, as related to space passed over, may be easily deduced. In the use of this instrument, the loaded weight is placed at the highest point of the course, and after the vibration of the diapason has been established, the weight is suddenly set free. So long as it is accelerated by its load, the rotation of the cylinder is accelerated in like manner. If the load is intercepted by a ring, as in Atwood's machine, the rotation becomes uniform, maintaining the velocity last

acquired; and these effects are visibly inscribed on the cylinder in the manner above explained. The cylinder admits of lateral displacement, so that several experiments may be performed before it becomes necessary to renew the covering of smoked paper. In order to mark with exactness the equal intervals of time, it is advantageous, before closing the circuit, to allow the cylinder to run while the diapason is at rest. The trace described will then be a line without sinuosities. Afterwards, when the original arrangement has been restored and the experiment is performed in the manner explained above, the undulating line described by the tracer will cross the mean line previously traced at exactly equal intervals of time; and these intersections will form more definite points of reference in measurement than are afforded by the summits of the undulations, since these necessarily become flatter and flatter in proportion as the velocity increases. This instrument cannot but prove to be a valuable contribution to the means of visibly illustrating the laws of gravity.

II.—PNEUMATICS.

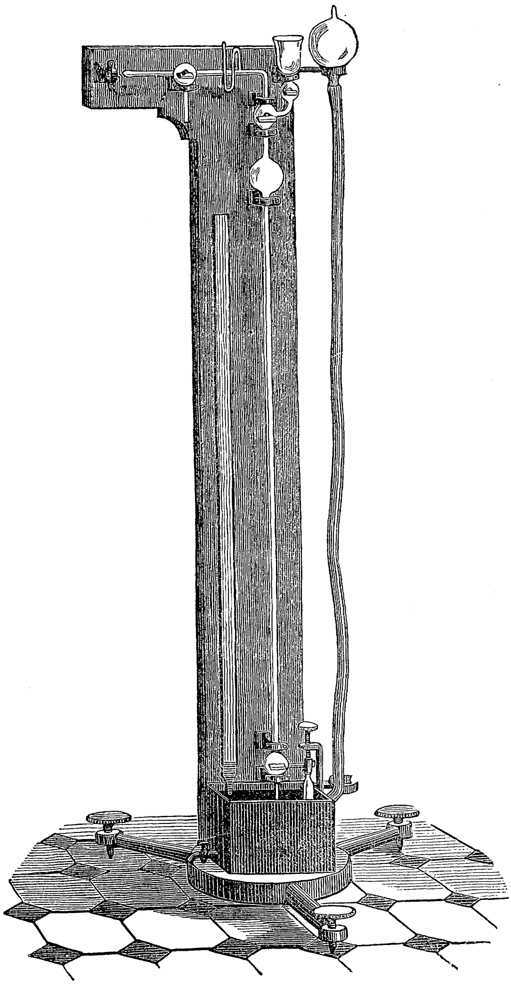
GEISSLER'S AIR-PUMP WITHOUT VALVES.

Several pneumatic machines designed both for exhaustion and for compression were present in the Exposition which deserve notice for their originality. Messrs. Alvergniat Brothers, of Paris, exhibited an apparatus called by them an "air-pump without valves," devised in the first instance, it is believed, by Geissler, and employed by him in the preparation of the tubes known by his name, but considerably modified in the details of construction by the present exhibitors. A variety of Geissler tubes were exhibited by this house, all of which were prepared by the use of this apparatus. The merit of this contrivance, of which the figure shows one of the simpler forms, consists in the fact that it suppresses entirely what is called by the French *l'espace nuisible*, and by the English, "dead space;" making it possible to continue the exhaustion without limit, or to make it as nearly absolute as may be required for any purpose.

The principal parts of this apparatus are, first, a glass tube, which must be as long at least as the barometric column, and which is enlarged near the top to a globe. The dimensions of this globe will depend somewhat upon the purpose for which the apparatus is to be used, but will be limited by considerations of the strength of the material, since, as the first step in the process of exhaustion, the globe is to be filled with mercury. At a little distance above the globe is placed a three-way cock, by means of which the globe may be put into communication either with the continuation of the tube above, or with a lateral branch which opens to the atmosphere. This lateral branch is surmounted by a funnel, or bell-shaped termination. The direct tube makes a right angle and is open at its extremity. A second simple stop-cock is placed

on its horizontal extension. The whole is firmly attached to an upright frame or plank. The open tube at top is to be connected by a caoutchouc continuation with the vessel to be exhausted. The lower extremity of the main tube is also open, and is connected with another stout caoutchouc tube, long enough to reach the level of the bell-shaped termination of the lateral branch above decribed. It is attached to a glass globe at least equal in capacity to the glass tube and its globular air chamber. At the top of the supporting frame is a bracket of suitable form to sustain this globe; and at the foot of the same support is another similar bracket, which in the figure is partially concealed by the caoutchouc tube.

Fig. 96.



Geissler's Air-pump without valves.

The mode of using the apparatus will now be easily understood. The proper connection having been made with the vessel to be exhausted, the uppermost stop-cock closed, and the large movable globe, or reservoir, having been filled with mercury, this last is placed on the upper bracket, as shown in the figure. The three-way cock is then turned so as to open communication between the upright glass tube and the lateral branch. The mercury descending the caoutchouc tube and rising in the glass tube, expels all the air from the apparatus, and enters the funnel; the use of which is merely to prevent its overflow. At this moment the three-way cock is again turned so as to close the lateral opening, and the movable reservoir is transferred to the lower bracket. On opening now the upper stop-cock, the air in the vessel to be exhausted will be rarified by the descent of the mercurial column, and a certain proportion of it will fill the apparatus. The cocks are then to be restored to their original positions and the reservoir placed once more on the uppermost bracket. This process is not rapid, and

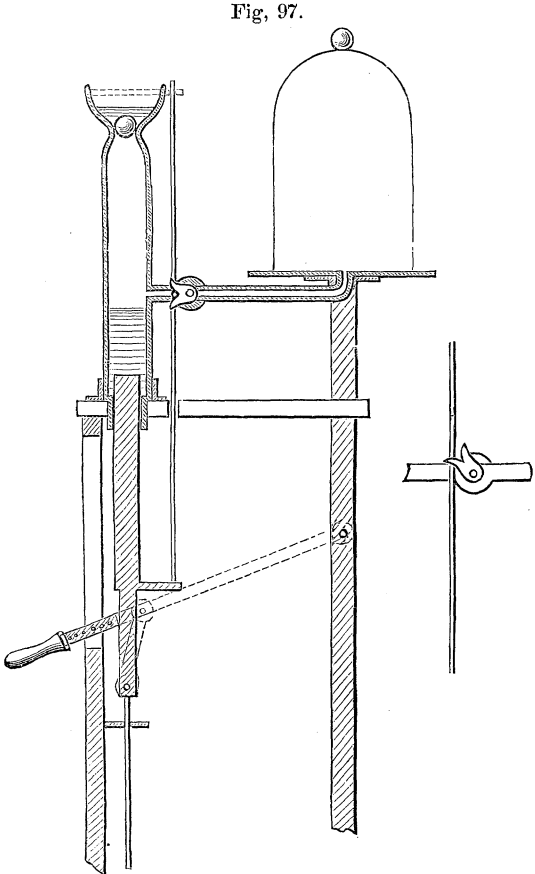
is employed only in the exhaustion of small vessels or tubes for laboratory purposes, or for the preparation of electrical apparatus.

A larger form of the same contrivance is employed by the Messrs. Alvergniat, in which the tube of caoutchouc is dispensed with, and the reservoir is attached to a rigid tube of iron, the whole being secured to a solid plank or frame which is hinged at the foot of the fixed upright. This facilitates the raising and depressing of the reservoir; an operation which is laborious, and which, when the reservoir is large, may even be hazardous.

KRAVOGL'S MERCURIAL AIR-PUMP.

An ingenious pneumatic machine, designed, like the one above described, to suppress the dead space which limits the efficiency of ordinary air-pumps, was exhibited in the Austrian section of the Exposition by Mr. J. Kravogl, of Insbruck. The principle of this machine will be best understood by reference to Fig. 97. It has a single cylinder, although it is capable of being constructed with more than one. This cylinder, which is of glass, is reduced at the top to a narrow neck, and is surmounted by a funnel. In the neck of the funnel is a valve opening upward. The cylinder contains a certain quantity of mercury. A plunger, of dimensions nearly equal to the capacity of the cylinder, enters it at the bottom and is raised in working so as to occupy it almost entirely. The mercury then fills the small annular space between the plunger and the wall of the cylinder, and also the space above the plunger up to the valve. By this means the air is completely expelled; and as the valve is covered by a small quantity of mercury in the funnel, there is no danger of leakage. A lateral tube connects the cylinder with the plate of the pump on which the receiver rests. The point of union with the cylinder is a little above

Fig, 97.



Kravogl's Mercurial Air-pump.

the level of the mercury when the plunger is at its lowest depression. Communication between the receiver and the cylinder is opened, when the plunger is in this position, by an automatic arrangement, of which one form is shown in the figure and will be easily understood, but which may take any most convenient form. The commencement of the upward movement closes this communication, which is not re-established again until after the air which has passed into the cylinder has been expelled and the plunger has once more returned to its lowest position. In principle, this machine is unexceptionable. Whether any unperceived disadvantage attends its operation in practice, will be determined by experience. It would be an obvious improvement to employ two cylinders instead of one. After the exhaustion has proceeded a little, the atmospheric pressure upon the plunger not only makes the working laborious in the downward movement, but makes it necessary to oppose a resistance to the upward stroke, except just at the close. This disadvantage does not exist in the large single-barreled air pumps of Ritchie, Deleuil, and others; because in those, the piston is not exposed to the returning pressure of the atmosphere. But while a piston may be shut up in a closed cylinder, a plunger cannot be conveniently so; and hence a pair of plungers counteracting each other by a connection like that of the pistons in the common double and open barreled air-pumps, would obviously be preferable to the single-barreled machine exhibited.

RICHARD'S AIR-PUMP WITHOUT VALVES.

Mr. F. Richard, of Paris, entered upon the catalogue of the Exposition an air-pump under the name above written. The machine is one of very large proportions, and it was not actually present in the Exposition; but its operation was witnessed in the workshop of the inventor, who obligingly explained its details and furnished drawings exhibiting its construction. The principle on which the efficacy of this machine depends is that of Babinet's double-exhaustion air-pump, but it is carried much further, so that the exhaustion as compared with that of a simple machine, instead of being, as in Babinet's pump, in the ratio of a constant to its square, is as the same constant to its eighth power.

A simple pump unprovided with any expedient like that described in the apparatus of Alvergniat, or the pump of Kravogl above described, for getting rid of dead space, can carry exhaustion only up to the limit expressed by the ratio of this dead space to the entire capacity of the working barrel, the dead space included. Or, if s represents the dead space, and S the total space, d the limiting density of the air in the receiver, and D the density of the atmosphere at the same time, it will be true in the last limit that,

$$\frac{d}{D}=\frac{s}{S}.$$

The reason of this is found in the consideration that no air can be expelled from the cylinder by the piston when its density at the termination of the stroke is only equal to that of the outward air. This is the

limit, even though the valves be opened mechanically and not by the elastic force of the air itself. But a quantity of air which, when occupying the space s, has the density D, will, when dilated to fill the larger space S, have evidently a density equal to $s : S$—a proposition which verifies the equation foregoing.

If, however, the air in the space s should have an opportunity opened to it of escaping, not into the atmosphere, but into another space $= S$, which is practically a vacuum, it would immediately assume a density $= s : S$ or $d : D$; and if the same state of things should continue to exist at the end of every stroke of the piston, the pump would be practically working not against an atmosphere of the natural density D, but against one of the reduced density $d : D$. And hence we conclude that exhaustion will go on until the final density in the receiver is to that against which it is working in the ratio $d : D$; while this latter is at the same time to the natural atmosphere in the ratio $d : D$ also. Or the ratio of density at final exhaustion to the density of the atmosphere at the same time is $d^2 : D^2$.

This result is obtained in effect in the double exhaustion pump of Mr. Babinet. The pump has two equal barrels, with pistons working alternately. One of these barrels discharges itself into the other, and this second one expels the air in this manner received into the atmosphere. This second pump, if worked alone, is capable of effecting an exhaustion of $d : D$. As the two work alternately, the first one throws its charge into this when the density of its contained air is minimum. That is to say, the first pump, or the one which communicates with the receiver, works against a density of $d : D$; which, as we have seen, is the condition necessary to produce an ultimate exhaustion equal to $d^2 : D^2$.

We have only now to suppose this principle extended to a series of barrels, and the exhaustion possible to be effected by the series will be expressed by the ratio $dn : Dn$; in which n represents the number of barrels. In the pneumatic machine of Mr. Richard, eight barrels are thus connected in a series. The barrels are also very large, having each the capacity of six and a half cubic decimeters, or four hundred cubic inches (nearly seven quarts.) Mr. Richard has also in operation a second pump of similar construction with only four barrels.

The object for which these powerful machines were built, was to subserve the purposes of an extensive manufacture, carried on by the inventors of manometers for indicating the pressure of steam or other elastic fluids, and of metallic barometers, similar in form to those which bear the name of Bourdon. In these instruments the essential organ consists of a metallic tube in the form of a horseshoe, having a cross-section of lenticular shape. Such a tube, when exposed to unequal pressures on its external and internal surfaces, varies its figure with the variations of pressure, the extremities of the horseshoe approaching each other with the increase of the external pressure, and *vice versa*. As constructed by Mr. Richard, these tubes are very sensitive to atmospheric changes, and fulfill admirably all the ordinary purposes of a barometer. It was for a

time a defect in the construction of these barometers that the tubes were deficient in elasticity and stiffness. Mr. Richard has happily overcome this difficulty, by the introduction within the tube of a steel spring of the same general form, which remedies the defect, and secures permanent uniformity of action. It is important that this spring, while within the tube and secured to it at both extremities, should not touch the interior walls. This condition the construction of Mr. Richard perfectly fulfills; and his barometers may be recommended to all who wish an accurate and portable instrument, as being admirable in workmanship and entirely satisfactory in performance. Mr. Richard constructs a variety of models of his barometer, from a size not larger than a watch to one not less than a foot in diameter. These instruments are not to be confounded with the so-called aneroid barometer, which, in outward form, they somewhat resemble, and which it is not intended to disparage while doing justice to the merits of their rivals later in the field. The aneroid barometers have a reputation for reliability which is believed to be well deserved.

The construction of Mr. Richard's eight-barreled air-pump may be gathered from the figures in Plate VIII. Figs. 1 and 2 in this plate furnish views in elevation; Fig. 1 an end elevation, and Fig. 2 a side elevation. Fig. 3 is a plan representing the relative positions and the connections of the cylinders. From this last figure, it will be seen that the barrels are arranged in two rows. Their places are marked A. Tubes of caoutchouc connect the barrels at their bases, indicated by the letters R and R′. The first cylinder in the front row on the right is connected with the vessel to be exhausted, by means of the caoutchouc tube R′, which is shown recurved toward the front. This cylinder communicates with the one immediately behind it, through a shorter tube R, also of caoutchouc, of which the direction is at right angles to the length of the machine. This second cylinder communicates, by means of the diagonal tube R′, with the next in order in the front rank; this with the second in the rear rank, and so on, until finally the last cylinder in the series communicates with the atmosphere by a valve opening outwards. Each one of the communicating caoutchouc tubes is bridged over by a bracket which is screwed down to the base plate. This bracket does not ordinarily compress the tube, but there is a piston beneath it, rising through the base plate of the cylinders, and carrying a broad cross-head, which, on being pressed upward, at a certain point of the movement of the pump, flattens the tube against the bracket, and closes the communication hermetically. A little consideration of the arrangement will show that it is necessary to the regular transmission of the air from the vessel to be exhausted, to the extreme cylinder marked A^2, and so to the atmosphere, that all the short direct communications shall be closed, while the diagonal ones are open, and *vice versa;* and also that all the pistons in the front rank shall be rising, while those in the rear rank are descending, and *vice versa.* Hence the pistons which compress the short cross-tubes must act simultaneously;

and in the mean time, those designed to act on the diagonal tubes will, for the moment, not be in action; but immediately after, the diagonal tubes will be compressed, and the short direct tubes will be relieved.

To show how these successive movements are effected, resort must be had to Figures 2 and 1. In Fig. 2, the direct tubes are shown under compression immediately in front of each cylinder, at R, R, R, R, and the diagonal tubes are shown in section uncompressed, at R′ R′ R′. The brackets over the tubes appear in this figure, marked *b′ b′ b′ b′*. The compressing pistons are also shown; those beneath R′ R′ R, in connection with the mechanism by which they are raised; and those beneath R, R, R, R, incomplete, being controlled by another mechanism which is not shown. In Fig. 1, however, the nature of this mechanism is shown for both sets of pistons.

To follow the connections of the gear-work, two cranks, N and N, at opposite extremities of the machine, by turning directly the pinions L, act on the gear-wheels K, and these gear-wheels, by means of a pinion I, on their common axis J, drive the gear-wheel in the middle of the mechanism, on the axis F. Upon this same axis F is the cam S, which, during half the revolution, acts through the lever *d*, turning on the pivot C′, and by means of the arm C^2, raises the piston B′, with the effect of compressing the tube R between it and the bracket *b′*. Upon this same shaft F are two additional gear-wheels, marked G, which drive a similar and equal pair, similarly marked, (Fig. 1,) on an axis F′, parallel to F. External to the gear-wheels G are strong cranks E, which, by means of the long connecting-rods D, move the cross-head which carries the pump pistons B. These cross-heads move in the guides S, and each one of them carries four pistons. The pistons themselves are constructed of dished leather. Upon the axis F′ is a second cam, S′, which acts on the lever *d′*, as S does on *d*, and effects the compression of the diagonal tubes R′, at the proper period of the revolution. By observing the arrangement, it will be seen that these two cams perform their office alternately, the figure showing S′ in action, while S is not.

From the gear-work connections it will be manifest that the motion of the pump pistons will be slow; but this is not a disadvantage, considering that the barrels are large and that the passages through which the air has to flow are narrow, while the velocity of flow, which decreases with the elasticity, becomes greatly reduced toward the close of the operation. The exhaustion effected by the pump, however, is extreme; and when the capacity to be exhausted is not great, it is sufficiently rapid. It makes about three strokes to the minute; and in a receiver of the capacity of two gallons it will produce a rarefaction to one four-hundredth of an inch of mercury in five minutes.

Other ingenious forms of valve have been employed by Mr. Richard in some of his pneumatic machines, which are illustrated in Figs. 6, 7, 8, and 9, Pl. VIII. Fig. 6 shows a discharge valve, *f*, which is maintained in place by the spiral spring *g*, aided by the pressure of the air in R, and

which is mechanically controlled by the stem *f f*. To prevent leakage from the superior pressure of the external air, the stem and the metallic tube *e* through which it acts are surrounded by a tube of caoutchouc, which is firmly bound to both, but by its elasticity leaves to the stem sufficient movement. Fig. 7 shows the base of the cylinder to which this valve is attached, as seen from above.

In Fig. 8 is seen a simpler and preferable form. In this, *a a′* is the duct through which the air escapes from the cylinder to the tube R; and J′ J′ is a plate of caoutchouc which is secured in place by the cap *k* screwed firmly down. A piston passing through the cap and operated mechanically, compresses the caoutchouc plate and closes the duct at the point J. If instead of a simple piston a screw be employed, this contrivance is a very effectual form of stop-cock.

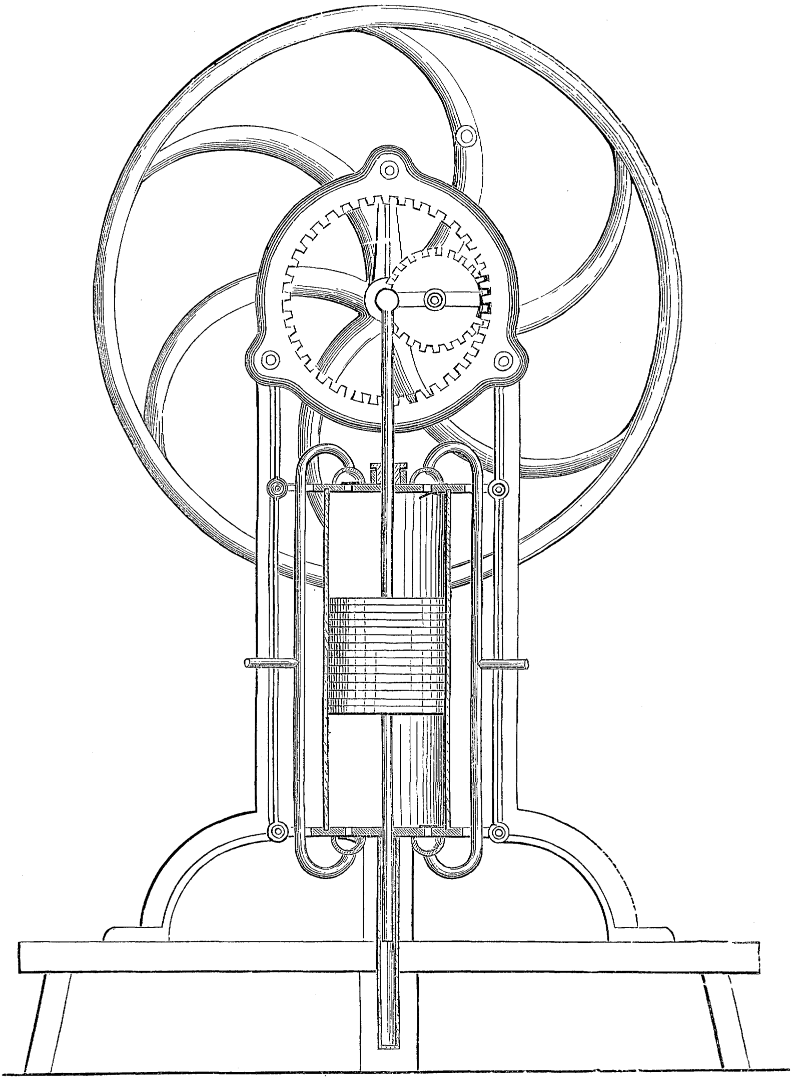
DELEUIL'S FREE-PISTON AIR-PUMP.

Probably the most remarkable pneumatic machine which appeared in the Exposition, or which has been yet constructed, is the free-piston air-pump, of Mr. J. A. Deleuil, of Paris. The peculiarity of this machine is that the piston works out of contact with the barrel of the pump, and of course entirely without friction. This piston is a metallic cylinder, and the barrel within which it moves is of glass. But though there is no contact between the surfaces, the space between them is exceedingly minute, being stated at the fiftieth part of a millimeter. It is of course necessary that the workmanship should be very superior, and that the strength of the whole machine should be such as to remove all danger of change of figure, or of any even very slight deviation of movement, or disturbance of the truly concentric adjustment.

The efficacy of this machine depends upon the difficulty and slowness with which gases make their way through very narrow spaces. The film of air between the piston and the wall of the cylinder is practically confined there, and forms a kind of lubricating cushion. The only resistance, therefore, which the piston encounters in its movement, is that which arises from the unequal density of the air above and below it. Fig. 98 shows this machine in elevation. The piston is driven by means of the epicycloidal combination of La Hire, operated by a crank and fly-wheel. It is guided by a rod extending entirely through the barrel at bottom as well as at top. There are two valves at each end of the cylinder, one opening inward and the other outward. The outward opening valves both communicate with the same tube, which is recurved and united with the cylinder at both extremities. At the middle point of this tube, a branch leading from it may be connected with a condensing apparatus; so that the pump may be used for compression as well as for rarefaction. When used for the ordinary purposes of an air-pump, however, this branch is open to the atmosphere. On the other side, the two inward opening valves are similarly connected, and the branch tube on that side establishes communication with the receiver to be exhausted. But when the pump is employed to compress air, this

branch is open in its turn to the atmosphere. The valves as drawn in the figure are operated by the elasticity of the air. But in the construction now given to this part of the apparatus, they are opened and shut mechanically by the piston itself. For this purpose, there are introduced two cylindrical rods passing through the piston and reaching from end to end of the cylinder, but capable of a slight longitudinal

Fig. 98.



Deleuil's Free-piston Air-pump.

movement as the piston changes its direction. This movement opens a valve at one end and simultaneously closes the corresponding one at the opposite end; but this change having been effected, the rod remains stationary, the piston sliding on it as it continues its movement. The

particular contrivance here described is not peculiar to Mr. Deleuil's pumps, however, as it has been often employed before.

The interior bore of the barrel must, of course, be very truly cylindrical and well polished. The piston is, in length, more than equal to its diameter. When the pump is used for compression, a greater length of piston is employed than is necessary for exhaustion. In point of fact, in this case, the difference of pressure on opposite sides of the piston becomes several times greater than it can be when the machine is employed only to produce a vacuum. There is no difficulty in carrying the condensation, in the course of a very few minutes, as high as five or six atmospheres. On the other hand, exhaustion is effected with remarkable rapidity. With a machine having a cylinder of four and a half inches in diameter, a twenty gallon receiver may be exhausted down to a pressure of less than half an inch of mercury in five minutes. Exhaustion may be carried lower than to the tenth of an inch of mercury.

The figure shows that the piston has not a continuously cylindrical surface from top to bottom. It is cut by grooves of very slight depth, and about half an inch apart. These grooves fulfill, apparently, a very useful function. Suppose the difference of pressure below and above the piston to be very great—the excess being, for example, below; the velocity with which the air tends to escape on the upper side, will be much less than that with which it tends to enter the narrow space between the piston and cylinder on the lower. But before this superior velocity can be transmitted beyond the first groove, this groove must be filled with air of density equal to that below the piston. And before the same velocity can be propagated beyond the second groove, this second groove must be filled in like manner. As the movement is slow even when the pressure is greatest, it will take a much longer time to transmit through all the intermediate grooves to the upper limit of the piston the tendency to movement which exists at the lower limit, than it would do if the piston were quite continuously cylindrical; and thus we have the paradoxical effect of a *packing*, produced not by *adding to* the substance of the piston, but by *taking from* it. It is found, in fact, that the working of the pump may be interrupted a sensible time without turning a stop-cock, and yet without vitiation, by the infiltration of air between the piston and cylinder, of the vacuum already secured.

III.—SOUND.

No branch of modern physical investigation has been productive of more numerous interesting results than acoustics. And in no branch of experimental inquiry have investigators been dependent for their apparatus upon a smaller member of able constructors. This subject was represented in the Exposition almost exclusively by a single exhibitor, Mr. Rudolph Kœnig, of Paris. On the other hand it may be said that Mr. Kœnig's exhibition was so complete and admirable as to leave nothing to desire. Inasmuch as the laws which govern the production and the mutual influence of sounds are strictly mechanical, they admit of being

demonstrated by methods which are not acoustic in the sense of being dependent on the sense of hearing; and accordingly the most striking illustrations of acoustic phenomena which have been recently devised, are addressed rather to the eye than to the ear. These are either graphic, being the permanent delineation, upon a properly prepared surface, of the path of a vibrating point; or optical, presenting the visible image of the same path, as seen through a microscope, or thrown in greatly magnified dimensions upon a screen; or, finally, optical and mechanical at the same time, exhibiting visibly the varying conditions of a vibrating body of air by the effect produced upon jets of flame.

At the same time, methods of investigation strictly acoustic in character have been pursued in recent years with great success; and in this branch of inquiry no one has made more valuable contributions to the ascertained facts of science, or to the instruments of research, than Professor H. Helmholtz, of the University of Heidelberg. One of the most interesting instruments exhibited by Mr. Kœnig was the *double siren* of Helmholtz. The simple siren of Cagniard de la Tour is well known, and may be described as consisting of a cylindrical brass box or wind-chest, into which a blast of air is introduced by a tube through the bottom, while the top is perforated by a series of equidistant apertures arranged in a circle. A circular plate, similarly perforated, turns freely on its center almost in contact with the top of the wind-chest, so that it alternately opens and closes the passages for the escape of the air, according as the two sets of apertures coincide, or the contrary. The apertures are inclined in direction in the same manner as the directrices and pallets of a turbine wheel; that is to say, so as to give to the escaping air the greatest effect in imparting rotation to the freely moving disk. When air under pressure is admitted to the wind-chest, the rapid succession of impulses produced by its intermittent escape generates a musical note which continues to rise in pitch until the increasing resistances balance the impelling force; after which the pitch remains constant. The axis of the disk carries a screw-thread by means of which a set of register dials may be operated, recording the number of revolutions made in a given time. This recording apparatus may be thrown into gear with the screw, or thrown out, at the pleasure of the experimenter. If it is desired to ascertain how many impulses to the second are necessary to produce a note of a given pitch, the wind pressure must be adjusted in such a way as to maintain that pitch steadily. Afterwards, the recording apparatus is to be thrown into gear and allowed to run for a determinate length of time, when it must be detached. The difference between the initial and final readings of the register will give the number of the revolutions of the disk; and this, multiplied by the number of perforations in the circle, will give the total number of impulses. Dividing then the number of impulses by the number of seconds embraced in the observation, there will be found the number of complete vibrations or sound waves per second, corresponding to the given pitch.

The siren invented in 1827 was improved by Opelt in 1834, by Seebeck in 1849, and by Dove in 1851. In these improved forms the revolving disk was provided with a number of sets of circular perforations, the object being to illustrate the effects of harmonic and interfering sounds, the coalescence of impulses from many sources in producing a single sound, the impressions resulting from impulses not isochronous, and the so-called combination tones occurring when the beats of discordant notes are too rapid to be separately distinguished by the ear. The most elaborate of these instruments is that of Seebeck, which was exhibited, in greatly improved form and on a large scale, by Mr. Kœnig. In this instrument the rotation is produced by mechanism, and not by the blast. The rotary disk may also be removed and replaced by another differently perforated; and instead of a wind-chest, twelve *port-vents* connected with an air reservoir or blowing machine, by means of caoutchouc tubes, are employed to conduct the air to the apertures in the disk. These, of course, admit of adjustment to the different series of perforations on which it is desired to experiment. There are nine different disks, and each one carries a number of circles of apertures, some of them as many as eight.

HELMHOLTZ'S DOUBLE SIREN.

The double siren of Helmholtz is the last and most interesting of the instruments of this class. It consists of two sirens, one of them placed in an inverted position directly over the other, and each constructed on the plan of that of Cagniard de la Tour, as modified by Dove; that is, having four concentric sets of perforations, provided with registers to allow of their being used together or separately, as may be desired. The two revolving plates are also connected by a common axis, and thus revolve together. In Dove's siren the numbers of perforations in the successive circles were eight, ten, twelve, and sixteen, corresponding to the tonic, third, fifth and eighth of the musical scale. In the double siren, one of the disks is perforated with eight, ten, twelve, and eighteen holes, while the other has nine, twelve, fifteen, and sixteen. The external circle on each disk gives a note which is the octave of that corresponding to the inner circle on the other. The second and third circles in each disk give harmonics of the inner one; and by combining the numbers in the two disks by pairs, many concords may be produced. But the most important peculiarity of this instrument consists in the introduction of a simple mechanism by means of which the upper cylinder or wind-chest may be rotated around its vertical axis while the instrument is in operation; a peculiarity which adapts it to many curious illustrations of acoustic principles. A crank acting through gear work, enables the experimenter to effect the rotation; and the extent of the angular advancement of the wind-chest at any moment, is shown by an index on a divided circle.

Supposing the air to be admitted to but a single circle in this upper cylinder, the lower at the same time not being in operation, and the pitch

having been made steady, the rotation of the wind-chest produces an elevation or depression of the pitch according as the direction of its movement is opposed to or in coincidence with that of the disk. In the first case the intervals between the impulses are shortened, and in the second they are lengthened, by the effect of the double motion, and the number per second is correspondingly increased or diminished.

When the air is admitted to the circles in the two disks which are similarly perforated, (those having twelve apertures in the circle,) the instrument admits of an instructive study of the effects of the interference of equal waves, or of the resultant sound produced by the superposition upon each other of waves of equal length but in different phases. When the openings in the two wind-chests are exactly in the same azimuths, the impulses coincide, and the intensity of the resultant sound is equal to the sum of the intensities of the separate sounds; but when the upper wind-chest is displaced from this position by turning the crank, the intensity of the sound diminishes in consequence of interference, until the angular displacement is equal to half the distance between the successive apertures, when the intensity is minimum. The same ingenious instrument serves for the investigation of the interferences of unequal waves, of combination tones, and of many other interesting acoustic phenomena.

HELMHOLTZ'S RESONATOR.

Another important acoustic instrument invented by Prof. Helmholtz is the *resonator*, an instrument designed to facilitate the analysis of compound sounds or notes. It has been clearly demonstrated by Prof. Helmholtz that scarcely a single sound in nature, and scarcely a note of music by whatever instrument produced, is made up of a simple series of isochronous impulses. Musical notes are accompanied by their harmonics, or, as the Germans call them, their over-tones. To the compound note thus produced they apply the term *clang;* to the simple note, *tone.* As the effect of a note upon the ear will be sensibly modified by the number and order of the over-tones which accompany it, we are accustomed to speak of these modifications without being conscious of their cause, as the *qualities* of sound; an indefinite term, which ought to be replaced by a better. Instead of quality, the French say *timbre*, the stamp or the ring; and the Germans, still better, *Klangfarbe*, sound color.

It is a curious fact that the notes which we call brilliant owe their *Klangfarbe* to overtones related to the fundamental, as the odd numbers, three, five, seven, &c.; while dull or muffled tones, such, for instance, as those of stopped organ-pipes, derive their character from overtones having ratios derived from two and its powers, four, eight, and so on. The brilliancy of the piano-forte is obtained by causing the hammers to strike the strings at a point about one-seventh of the total length from the end. The contrast of character between the note thus produced and that which is obtained by striking the string in the middle is very strongly marked.

When the air within a confined space, as a tube, is set into vibration, there is produced a clang, and not a tone. The fundamental tone in the clang is that which corresponds to the smallest number of vibrations per second of which the mass of air is capable. In an ordinary organ pipe it is almost impossible to produce a tone without a clang. It can only be accomplished in the case of stopped pipes of large cross section feebly blown. But Helmholtz has found that a spherical or nearly spherical cavity, or a wide and short cylindrical tube narrowed at the end, will have a strong fundamental tone ordinarily heard alone; and that the overtones of such a cavity are excited with difficulty, and when excited are very faint. Upon this fact rests the construction of the resonator, which is shown in the accompanying figure. This is nearly spherical in form, having an opening on one side to the air, and a tube at the other, which is adapted to the ear. Supposing this instrument carefully fitted to one ear, while the other is stopped against all sounds, it will be observed that most of the words of ordinary speech, and most musical notes, are only faintly heard. But whenever the speaker or singer happens to strike the peculiar or *proper* note of the resonator, the sound will be so suddenly and singularly reinforced as to be almost startling. Now this effect occurs not only when the proper note of the resonator corresponds to the fundamental note of a clang, but also when it corresponds to an over-tone. It is possible, therefore, by means of a series of resonators, adapted to all varieties of pitch, to *analyze* the clang-sounds of music, and to find out what is that kind of composition which imparts to the notes of different instruments their characteristic quality, *Klangfarbe*, or sound-tint. This Professor Helmholtz has done; and he has shown that the simple *tones* which make up any clang, when separately heard in their proper resonators, are perfectly indistinguishable as to quality, whether they proceed from wind or from stringed instruments, from brass or from wood, from reeds or from open embouchures. Each resonator of Helmholtz is adapted to the detection of only a single tone, but this ingenious experimenter has succeeded in the construction of a compound resonator formed of three tubes sliding one within the other, by means of which the volume of air may be varied so as to adapt it to tones of different pitch. By one of the sliders large variations may be made, while by the other, which is governed by a rack and pinion movement, the instrument may be adjusted more exactly to the pitch which the first adjustment only attains proximately. It has been found practicable even to construct a resonator capable of being changed in pitch by opening and closing holes with the fingers, as in playing upon a valve

Fig. 99

Helmholtz's Resonator.

trumpet or clarionet; and the curious consequence follows, that an experimenter armed with this instrument may, in the confused roar of a cataract or of a crowd, regale his ear with a melody inaudible to others, by sifting as it were the proper notes out of the general din. The instrument, from the fact that it originates no sound itself, has been called the *melodeon aphone*, the voiceless melodeon.

Resonators are constructed by Mr. Kœnig of great variety of pitch. He furnishes for demonstrations a series of nineteen, embracing the principal harmonics from C in the bass clef to E in the third octave above.

SCHEIBLER'S TONOMETER.

A striking part of the exposition of Mr. Kœnig was also Scheibler's tonometer, an apparatus for determining the exact number of vibrations concerned in producing a given tone, and also designed for use in tuning musical instruments. In this latter application it enables a person without the slightest pretense to a "musical ear," to tune any instrument as accurately as the most accomplished musician. Scheibler's original apparatus consisted of sixty-five sounding-forks, or diapasons, beginning with C in the treble clef, a pitch corresponding to 512 simple vibrations, and extending to the C above, corresponding to 1,024 simple vibrations. There are therefore sixty-four intervals, and as the numbers of vibrations increase in a uniform arithmetical series, the common difference is eight. Any two of these diapasons adjacent to each other when sounded together will give four *beats* per second. To determine, therefore, the pitch of a given string, its note is compared with the notes of the diapasons nearest to it in sound. By counting the resulting beats it will soon be referred to a place between some given two of the series, and then, by comparing the number of beats made with *each* of these two successively, its *exact* place will readily be inferred. In tuning a string to a given pitch an analogous process is pursued. If the string is to have precisely the same pitch as one of the diapasons of the series, it is not compared with that one, but with the one immediately above and the one immediately below. It must be so strained as to beat four times per second with either. If it is to be half-way between the two, it must be brought to beat twice per second with each. If it is to divide the interval as one to three, the number of beats must be one per second with the nearest and three per second with the other. Thus, if a string is to be tuned to the pitch A in this octave, this will require, as referred to the English concert pitch, 888 simple vibrations to the second, and will correspond exactly to the forty-seventh diapason of the series. The comparison must therefore be made with the forty-sixth and the forty-eighth. Referred to the French standard it will require 870 vibrations to the second. The forty-fourth diapason gives 864 to the second, and the forty-fifth 872. The desired pitch divides the interval (8) into two lesser intervals, which are as six and two, or as three and one. It must therefore make three beats with the forty-fourth diapason and one beat with the forty-fifth.

The Scheibler tonometer, as exhibited by Mr. Kœnig, was extended greatly beyond the limits above indicated, and was, in fact, made to cover the entire range of audible sounds. Thirty-two (thirty-one perhaps more exactly) simple vibrations, or sixteen successive sound waves, per second, is the smallest number which produces a continuous impression upon the ear. The upper limit of audible sounds was fixed by Savart at forty-eight thousand per second. Helmholtz placed it as low as thirty-eight thousand. Marloye imagined that he had proved it to be not lower than sixty-four thousand; but the laborious experimental determinations of Kœnig have demonstrated that it is not constant in different individuals, and that it is in general between forty-five thousand and fifty thousand. With advancing age, sensibility to sounds of more than thirty-two thousand simple vibrations per second diminishes.

Kœnig's extended tonometer, as exhibited, embraced three hundred and thirty diapasons, carrying the pitch up to 4,096 simple vibrations per second. To these were added eighty-six straight steel rods for the higher pitches from 4,096 to 8,192 vibrations; these two series united embracing the entire range of notes employed in music. For tones still higher he had added rods corresponding to wider intervals than those of the tonometer proper, and representing only the notes of the common chords of the next three superior octaves.

For the four lowest octaves of the tonometer there were provided only two diapasons each; but these were made in effect equivalent to sixty-five by having weights attached, which, sliding up and down upon the limbs, and being fixed by clamps at pleasure at the different points of a scale divided into sixty-four parts, produced as many variations of pitch within the limits of the octave. Thus the heaviest pair, which gave the notes corresponding to the numbers from 32 to 64 per second, would furnish intervals differing by only half a simple vibration, or one beat in four seconds. The second pair (64 to 128) gave intervals of one vibration, or one beat in two seconds. The third (128 to 256) gave intervals of two vibrations, or one beat per second; and the fourth (256 to 512) gave intervals of four vibrations, or two beats per second.

After these came the series of sixty-five diapasons, giving four beats per second, and going up from 512 to 1,024.

From 1,024 to 2,044, eighty-six diapasons, or eighty-five intervals of twelve vibrations each, very nearly complete the octave from C^2 to C^3. The exact octave C^3 would be 2,048. These intervals give six beats per second.

From 2,044 to 4,096, there are required, for intervals of the same magnitude and giving the same number of beats, one hundred and seventy-two diapasons and one hundred and seventy-one intervals.

After this come the straight rods, which are substituted for diapasons on account of the increasing difficulty of construction for notes of so high a pitch. These are excited by rubbing, and the pitch is that which corresponds to longitudinal vibration. The number of these is

eighty-six. The intervals are forty-eight vibrations, giving twenty-four beats to the second.

Ten more rods give respectively 8,192, 10,240, 12,288, 16,384, 20,480, 24,576, 32,768, 40,960, 49,152, 65,536, simple vibrations to the second; corresponding to the notes C^5 E^5 G^5 C^6 G^6 G^6 C^7 E^7 G^7 C^8. The sound C^8 is inaudible to all persons, as is probably G^7. These ten vibrate laterally.

GRAPHIC REPRESENTATION OF VIBRATIONS.

The graphic method of observation of the vibrations of sounding bodies, consists in attaching to the body under examination a delicate tracer, adjusted so as to touch lightly a smooth surface which has been blackened over a smoking flame. This surface is made to move uniformly under the touch, and the tracer leaves behind an undulating path, of which the form varies with the character of the vibration. To show the effects of combined parallel vibrations, equal or unequal in time, two diapasons may be used, both placed horizontally, with their stems in opposite directions, and with the planes of their forks also horizontal. The surface on which the trace is to be made is attached to one limb of the lower diapason, and the tracer to the corresponding limb of the upper. Then both of them being excited, the one which carries the tracer is moved steadily in the common direction of their lengths, and the trace exhibits the resultant effect of the vibration.

When the resultant of two vibrations at right angles to each other is to be obtained, the two diapasons are placed so that their axes may be at right angles; but in other respects, the arrangements above described remain essentially unaltered.

Another mode of obtaining graphic representations of the movements of vibrating points is to wrap a sheet of smooth paper round a cylinder which is provided with a clock-work movement; and then, having prepared its surface in the manner above mentioned, to bring the tracer into contact with this surface. By giving to the cylinder a gradual movement in the direction of the axis, which may be effected by means of a coarse screw-thread on the axis itself, the trace will form a spiral on the cylinder, and the entire sheet of paper may be made available for experiment without troublesome adjustments.

This method of studying vibrations has been generalized in the instrument called the phonautograph, or phonograph, by Scott and Kœnig, an instrument in which the tracer is moved by the vibration of a circular stretched membrane, which is itself excited by sonorous waves proceeding from any sounding body, as a bell, a diapason, a musical instrument, or the human voice. In order to intensify the impulses upon the membrane, this is fixed in the focal point of a large hollow paraboloid, truncated at the apex. The sounding body is placed in front of the paraboloid, and the receiving cylinder is brought into a convenient position at the opposite extremity to receive the trace. With this apparatus very interesting results have been obtained. In

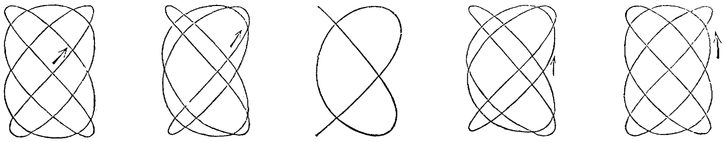
order to determine the *time* of vibration of the several sounds under examination, as well as the forms of the paths, a diapason of known pitch, placed near the receiving cylinder, traces an independent curve, the undulations of which serve as time markers. Instead of a paraboloid, Mr. Scott originally employed a large ellipsoid, placing the sounding body in one focus while the membrane occupied the other. This form of the apparatus is convenient for some purposes, and it has the advantage of giving a more powerful reflection; but for experiments on musical instruments, or on sounds proceeding from bodies which cannot be conveniently introduced into the cavity, it is less convenient than that above described.

Mr. Kœnig not only exhibited these instruments, but also a very interesting album containing a great variety of curves of curiously complicated but symmetrical character which had been traced by means of them, showing how the over-tones of clangs manifest themselves as superposed upon their fundamentals; how vibrations of slightly unequal times alternately extinguish and reinforce each other, (giving in fact a visible picture of the beats,) and serving in many other respects as a curious and instructive study.

The optical method of investigating vibrations was first employed by Lissajous, and was described by him in a communication made to the French Academy of Sciences in 1855. He has since considerably modified and perfected it. It will be understood by supposing a small mirror of polished metal to be attached to one limb of a diapason, fixed by its stem in a firm stand, and placed in a dark room into which a ray of sunlight is admitted through a small aperture. The ray is received upon the mirror and reflected upon a white screen. To give sharpness and brilliancy to the image, the light is made to pass through a convex lens of long focus, which is suitably adjusted to bring the focal point upon the screen. If the diapason is then excited, the slight movement of the mirror will be greatly magnified in the image upon the screen; and owing to the persistency of the impression on the eye, the point will be apparently transformed into a straight line. If now a second diapason similarly provided with a mirror be interposed in the path of the reflected ray, a second reflection will take place; and if the new image be similarly received upon a screen while both diapasons are vibrating, the path described may take a variety of forms dependent on the position of the axes of the diapasons, upon their times of vibration, and upon the relation of the vibrations to each other in respect to phase. Supposing the two axes at right angles, and the phases identical or opposite, while the times are equal, the visible path will still be a straight line; but it will be inclined at an angle of forty-five degrees to the directions of the two component vibrations. Supposing that the phase of one is one-quarter advanced upon that of the other, the result will be a circle. All the other relations of phase will in this case give elliptical figures. When the times of vibration are different, the paths described are much more

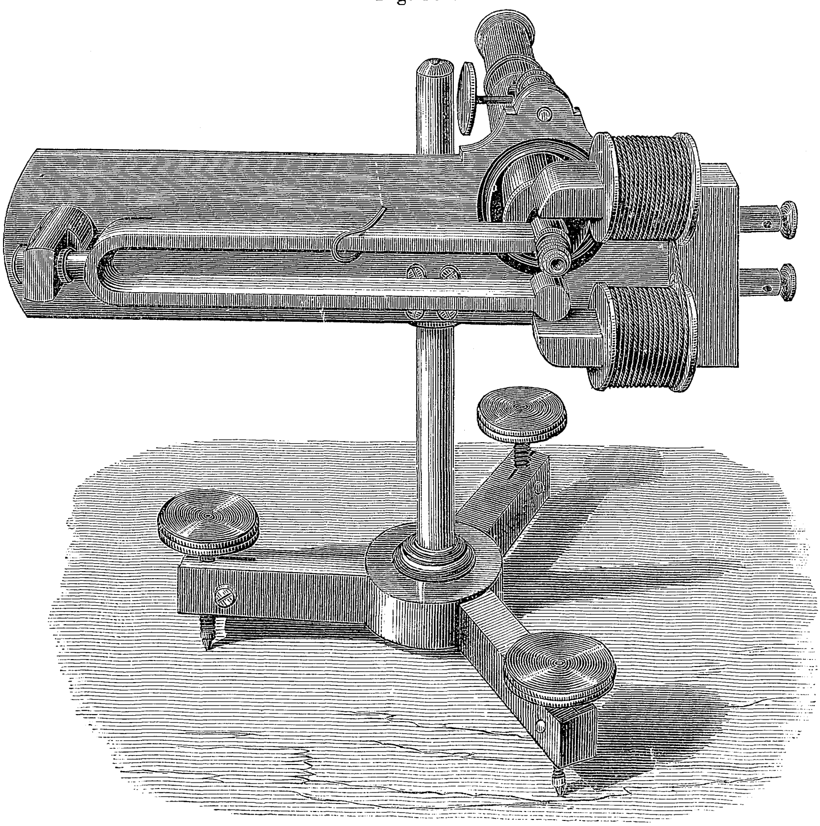
various, increasing in complication with difference of phase, according as the ratios of the times are expressible by less and less simple numbers. The diagram annexed represents some of the figures obtained with two

Fig. 100.



diapasons whose times are as three to four, representing the chord of a fourth. The first of these appears when the initial difference of phase is zero; the succeeding ones correspond to differences of phase equal to the fractions $\frac{1}{24}$, $\frac{1}{12}$, $\frac{1}{8}$, and $\frac{1}{6}$ of the larger vibration; that is to say, they make their appearance if, when the shorter vibration begins, the longer is advanced by the amounts of these several fractions.

Fig. 101.



Lissajous's Comparator.

The apparatus here described is adapted to exhibit the vibration figures to several observers at once. But as it may sometimes be desira-

ble to study the vibrations of bodies to which mirrors cannot be attached, as for instance, of stretched strings, Mr. Lissajous has contrived an ingenious apparatus which he calls his comparator. This, which is represented in the accompanying figure, consists of a diapason, to one limb of which is attached the object glass of a compound microscope; the body of the microscope being detached and supported by an independent stand. If the diapason be thrown into vibration, the image of any small object seen through the microscope will appear to have a similar motion, which will be magnified by all the power of the instrument. Let the object be itself a point in a vibrating body, having its direction of vibration at right angles to that of the object-glass, and the combination of the two motions will produce figures, from the analysis of which the character of the vibration of the body observed may be deduced. When the vibrating body is a string, or other object without conspicuous points suited to be used in the comparison, it is necessary to mark it in some manner. Different observers have adopted different expedients for this purpose; but in order to avoid loading the body or altering its condition by adding coloring matters, Mr. Lissajous, in the case of strings, has employed a cylindrical lens to throw a sharp line of light across the object. This creates a brilliant point moving with the string without in any manner disturbing its mode of vibration.

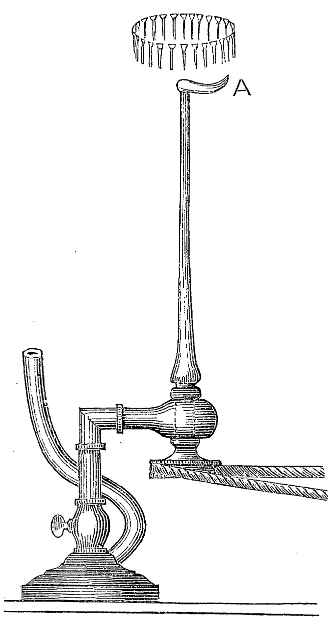
In order to maintain the vibration of the diapason for an indefinite length of time, without being under the necessity of exciting it mechanically, Mr. Lissajous has also introduced an electro-magnet to act intermittently upon one of the limbs, the circuit being alternately closed and broken by means of an interruptor carried by the limb itself. The manner of making electric connection with the limb is shown in the figure; but the interruptor itself, which is a short bent wire attached to the end of the limb, and dipping into a cup of mercury, is not represented.

ACOUSTIC FLAMES.

The acoustic methods founded on the mechanical effects of vibrations in the air upon gas flames are among the most recent as well as most remarkable contributions to this branch of investigation. It has long been a familiar laboratory experiment to excite musical notes in a tube by holding it over a burning jet of hydrogen gas. The explanation originally given of this phenomenon was to attribute it to the intermittent condensation of the watery vapor generated by the combustion. Faraday showed, however, that the sounds continued to occur, though the apparatus and the air in the tube were raised to a temperature above 212° F; and that carbonic oxide might be substituted for hydrogen without preventing the success of the experiment. The true cause is probably the friction of the gas against the orifice through which it escapes; though Professor Tyndall ascribes it to the friction of the air against the flame. Professor Tyndall has himself shown that a long upright tube filled with water and discharging itself through a small orifice at the lower end, will emit a soft musical sound as the water

descends. The movement of bodies rubbing against each other is never steadily continuous; but the effects of inertia or other controlling causes often render the alternations of acceleration and retardation synchronous and regular. If these intervals correspond with the natural vibration-times of the rubbing bodies, or of others in contact with them, very slight forces may by gradual cumulation produce striking effects. The friction of a jet of gas against the orifice by which it escapes, may be insufficient in itself to excite vibration in the column of air contained in the tube surrounding it; but when the flame is present, the inequalities in the development of heat occasioned by the varying rapidity of combustion furnish a large reinforcement to the original sole disturbing cause. The very slight and at first even imperceptible tremor of the air thus produced reacts itself upon the combustion, constantly increasing the inequality just spoken of, as is even visible in the flutter of the flame, and the vibration becomes presently strong enough to be audible. Professor W. B. Rogers, of Boston, supposes that the immediate cause of the vibration is to be found in the periodical explosive combustion of the gas, and that the cause of the periodicity is the variable rapidity of escape of the gas from the orifice, which is imputed above to friction. Perhaps this theory might be regarded as the most plausible, if the facility with which the sounds are produced by carbonic oxide were sensibly less than is the case with coal gas. The question may be considered to be still, to a certain extent, unsettled.

Fig. 102.



Rogers's Revolving Jet.

It is a curious fact that when a tube is thus excited to sing by means of a flame, the flame itself, though seemingly constant, is actually extinguished and re-kindled at every vibration. The proof of this was first shown by Professor Tyndall, by means of an optical arrangement extremely simple in itself, though very striking in the effects it produces. The experiment is made in a dark room. The tube employed is blackened in every part except on one side just opposite the point where the gas jet is to be placed. In front of the tube at this point is placed a concave mirror which is capable of being turned around a vertical axis. A screen is also adjusted at a distance suitable to receive the image of the flame produced by the mirror. So long as the tube is silent, as it will usually be when the flame is larger than the experiment requires, the rapid oscillation of the mirror around its vertical axis will produce upon the screen the appearance of a continuous band of light; but when, by gradually reducing the flame, the tube is made to sing, this band will be immediately broken

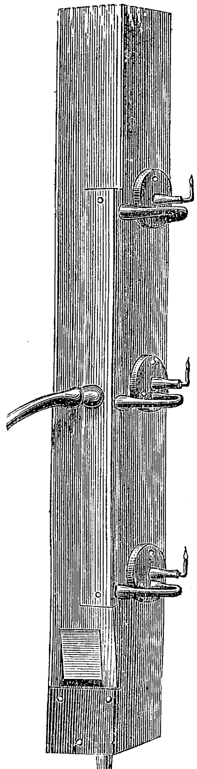
up, and in its place will appear a row of entirely separate and distinct images of the flame. Professor Rogers has very beautifully varied this experiment by dispensing with the mirror, and employing a bent gas tube, which is made to revolve rapidly within the singing tube of glass by means of a pulley and band as represented in the figure. The glass tube may be several inches in diameter; but the experiment succeeds perfectly with one of two inches. When the jet is put into rotation while the tube is silent, the flame forms a continuous circle; but the moment the tube begins to sing, the circle breaks up into a crown of minute flames, resembling a string of pearls.

Mr. Kœnig presents a pretty variation of this experiment. In every tube there are one or more points where the presence of the flame excites the note with greater facility than elsewhere. There are other points where the sound is excited only with difficulty, or not at all. Between these there may be found, by trial, points which may be called points of unstable equilibrium, where the tube is just ready to sing, but needs, as it were, to be helped. When a tube is in this condition, it is sufficient to strike its proper note with the voice or with an instrument, and it will immediately respond. A tube can thus be spoken into music from a considerable distance. Mr. Kœnig prepares two tubes of the same pitch, into one of which he introduces the revolving jet, while the other one has a fixed jet. The first of these is brought almost to the singing point, and the jet is put into revolution. The appearance presented by the flame is of course a continuous circle. The other tube is then brought to the singing point; and the moment its note is heard, the first responds, and at the same time, in place of the luminous circle, displays its string of pearls.

Mr. Kœnig also prepares the apparatus of Schaffgotsch, for demonstrating the mutual influence of singing flames. A small gas jet is placed at a little distance beneath a circular burner, open in the middle in the manner of an Argand's lamp, which carries a ring of jets. Another similar small burner is placed within a tube of glass at the point proper to excite it to sound. This and the small exterior jet are lighted, but not the circular burner. If the jet in the tube is too feeble to excite the note, the tube may nevertheless be made to sing by striking the note with the voice; but the reaction of the vibration upon the flame will be so strong as to extinguish it. By re-lighting it and giving it greater power, it will start the note itself, and then the effect upon the external flame will be such as to make it apparently leap up and become extinct in turn; but in the mean time it will light the circular burner above it. Another apparatus of Count Schaffgotsch consists in a pair of tubes slightly out of unison, each being provided with its own singing flame. When these are both excited near to each other, the beats produced by the discord will be very audible; and simultaneously the intervals of the beats will be visibly marked by corresponding oscillations of the flames.

Mr. Kœnig has also availed himself of the sensibility of flames to vibration, to illustrate the difference of condition of the several parts of a vibrating column in a tube, by marking the points of the nodes and the positions of the ventral segments. Tubes prepared for the purpose were exhibited by him, one of which is shown in the accompanying figure. To the side of the tube are affixed little gas-chambers with a jet attached to each, the chamber being closed on the side toward the vibrating column by a thin membrane. In the figure, three such "manometric" chambers are represented; one of them occupying the middle point of the tube, which (the tube being open at both ends) is the place of the node when the fundamental note is sounded. The other two divide equally the two halves of the tube, and mark the points where the nodes are formed in sounding the octave. The jets being lighted, a violent agitation of the central flame takes place whenever the sound of the fundamental note is heard, while the other two flames are but slightly disturbed. But on striking the octave, the middle flame comes to rest, and the agitation is transferred to the other two. This will be understood by considering that, at the place of the node, the air is alternately condensed and rarified without any motion of translation. When the node is in the middle, there is some variation of density at the points where the other flames are placed, but not very much. When the nodes are formed at these points themselves, however, they become the centres of the greatest changes of density, while in the middle of the column the motion is vibratory, but the density remains unaltered. If the flames are made very small, the sounding of the fundamental note quite extinguishes the middle one, but leaves the others burning. On the other hand, the octave extinguishes the extreme flames without affecting the middle one.

Fig. 103.

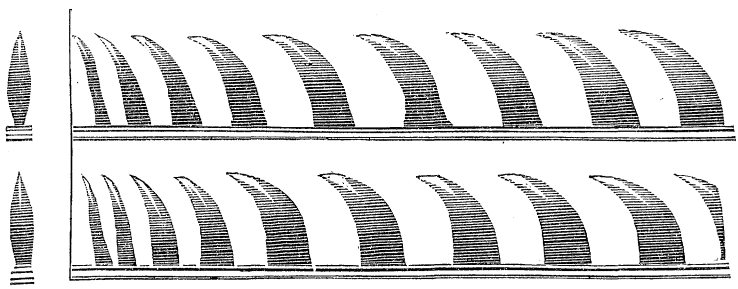


Kœnig's Nodal-point Manometric Flames.

Mr. Kœnig has also adapted this method to the visible illustration of the *interference* of sounds. It has long been known that if two organ pipes perfectly in unison be placed side by side and sounded at once, their united notes are sensibly less forcible than when they are placed at some distance from each other. The reason of this is, that they mutually influence each other to vibrate alternately; that is to say, condensation takes place at the nodes of the one, at the same moments at which the opposite condition exists at those of the other. The sound-waves produced in the surrounding atmosphere by these two vibrating columns are therefore in condition to interfere, so that to a certain extent they neutralize each other. The visible demonstration of this state of

things is furnished by attaching to the centers of the two tubes a pair of manometric gas jets like those just described, and bringing the flames one directly under the other. This may be done by suitably bending the small gas tubes which communicate with the manometric chambers. On sounding the tubes both flames will be agitated, but direct observation will not permit the phases of their varying brightness to be distinguished. But if a plane mirror placed by the side of the jets be rapidly revolved around a vertical axis, each of the apparently single flames will be resolved into a row of separate flames; and then the fact will be manifest that all the separate images in each row fall into the dark intervals between the images of the other row. The appearance presented by these flames is shown in the annexed figure. When one of

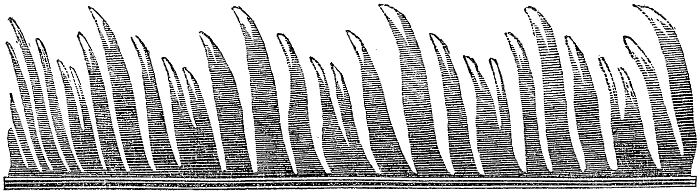
Fig. 104.



Manometric Flames—tubes in unison.

the tubes sounds a harmonic of the other, the images arrange themselves in a manner analogous; but the relations of the flame-images become less apparent as the ratios of the concords are less simple. By employing only one flame, however, and bringing it into connection with the manometric chambers of both tubes at the same time, a compound image is produced, in which the mutual influence of the vibrations makes itself manifest. The figure here given is a representation of the

Fig. 105.



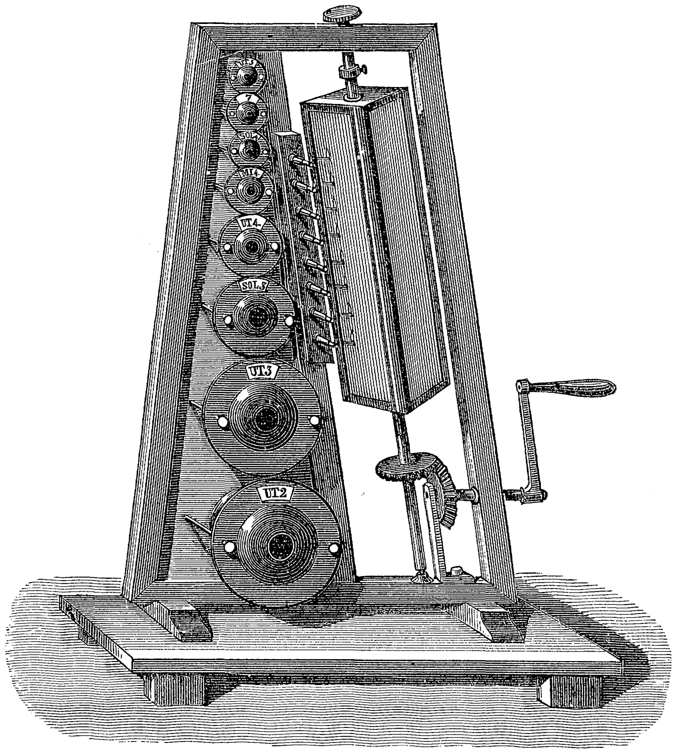
Manometric Flames—the tonic and the major third.

appearance presented when the tubes employed give the fundamental and the major third, having the harmonic relation of five to four.

One of the most interesting of the instruments exhibited by Mr. Kœnig, was his "Clang-Analyser," an instrument designed to demonstrate visibly the presence of harmonic overtones in all musical notes.

This is composed of a series of resonators, eight in number, adapted to a series of tones beginning with C°, or C below the treble clef, and embracing the octave, the twelfth, the fifteenth, the seventeenth, the nineteenth and the twenty-second. These resonators are arranged one above another, as shown in the figure, opening all in a common direc-

Fig. 106.



Kœnig's Clang-Analyser.

tion. A caoutchouc tube from the opposite extremity of each is conducted to a separate manometric chamber, having a gas jet attached. The gas jets are all arranged in a straight line, and parallel to them a mirror (four mirrors, in fact, forming a quadrangular solid) is mounted upon an axis, round which it is made to revolve rapidly by means of a crank and gear-work. The use of this apparatus hardly requires to be explained. When a musical note is sounded while the mirror is in revolution, all the tones contained in the clang will be immediately detected by the breaking up of the corresponding flames; while the absence of others will be equally demonstrated by the fact that their flames appear in the mirror as continuous unbroken luminous bands.

Besides the instruments above described, Mr. Kœnig exhibited Helmholtz's apparatus for demonstrating the different acoustic characters of the vowels as uttered by the human voice; which he has shown to result from the unequal predominance of the over-tones in these several sounds.

He exhibited, likewise, one or two forms of chronograph, in which the measure of time is effected by the undulating curves traced in the manner already described upon a revolving cylinder, by means of a delicate point carried by a diapason. In one of these chronographs the vibration is kept up by electro-magnetism, as in the acoustic comparator of Lissajous described above; and in another, by what may be called the sympathetic method, which may be thus explained. Two perfectly equal diapasons are fixed to a common iron support, one of them directed upward and the other downward. It is this last that carries the tracer. The upper diapason is mechanically excited by the hand or by a violin bow; and the other, in consequence of their perfect unison, takes up the vibration. As the first may be touched from time to time without interfering with the chronograph, it is easy, with a little attention, to maintain the vibration for any period.

In the array of apparatus exhibited by Mr. Kœnig were embraced, of course, many instruments and appliances for acoustic illustration and investigation which have not been enumerated here, such as plates, rods, cords, tubes, &c., most of which are familiar.

WESSELHOFT'S UNIVERSAL VIBROSCOPE.

An instrument of some interest was exhibited by Mr. Wesselhoft, of Riga, and called by him the "Universal Vibroscope." The design of this is to enable an observer to make direct observation of the motion of a vibrating body, whatever may be its nature, and under any circumstances. It is founded upon the principle of the well-known optical toy called the phenakisticope; that is to say, the essential part of the instrument is a rotating disk, perforated near the circumference with equi-distant sight holes. Suppose, for instance, that an observer, with this disk before his eyes, directs his attention to a singing flame or a vibrating rod. If the duration of the vibration is just equal to the interval between the passages of the succesive sight holes before the eye, the aspect of the flame or of the rod will be unchanged. Thus, if the rod happen to be caught at the point of extreme flexure on one side of the mean position, it will appear to be a permanently bent rod. And if the flame should be on the point of extinction when first seen, it will seem to be a steadily faint flame. But such an exact coincidence of intervals could hardly occur. The object will therefore be seen at its successive reappearances, in as many successive conditions; and owing to the persistence of impressions upon the eye it will not have been consciously lost sight of at all. The vibration, therefore, which is really rapid, will appear to be a motion comparatively deliberate, and the form of the path may be easily inferred. As it is necessary that the rotation of the disk should be rapid, it should be made of light material. The instrument exhibited was constructed of aluminium blackened. Card board would answer equally well in many observations of this description. Some magnifying power is desirable. This is furnished by a small tel-

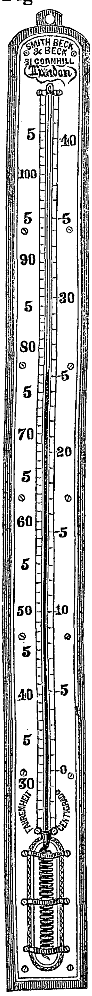
escope mounted on an independent stand, and brought close to the revolving disk on the side opposite to the observer's eye.

This instrument may serve as a means of determining the *rapidity* of vibration of the body observed. To this end it should be provided with a contrivance for regulating the velocity of rotation according to circumstances, and should have a register of its actual velocity during the time of observation.

IV.—HEAT.

THERMOMETERS.

Fig 107.



The display of thermometers by several exhibitors was very fine. The most remarkable were those of Mr. Richard Danger, some of which command a large range of temperature and are beautifully graduated, the tube containing the fluid being divided on one side and enameled on the other to make the marks conspicuous, and the whole being surrounded for protection by an enveloping tube sealed to it above the bulb, which remains exposed. Among a number of the thermometers of Mr. Danger were several in which the graduation is carried to tenths of a degree, the divisions still being so large as to be easily distinguishable. These are unprotected. The exposition of Mr. Danger embraced a variety of delicate articles in glass, remarkable for their beauty. Of these were particularly noticeable his graduated pipettes, with glass stop-cocks, of which the neatness and elegance are no less admirable than the skill of their execution.

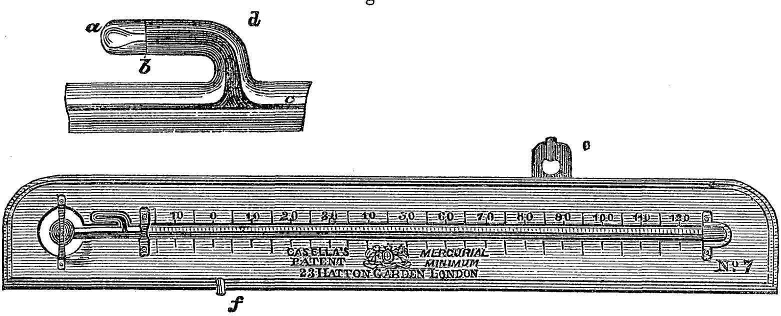
Messrs. R. & J. Beck, of London, presented also a beautiful display of thermometers. Some models in this exposition were designed with a view to increase the sensitiveness by making the surface of mercury exposed to the influence of the external heat very large in proportion to the mass. This is accomplished by substituting for the ordinary bulb a tube coiled in spiral form, either flat or elongated. The annexed figure, Fig. 107, illustrates the second form of this instrument, which, aside from its practical superiority, is very tasteful in appearance.

Mr. Baudin, of Paris, exposed a series of thermometers in which the sensitive fluid employed is alcohol tinged with a variety of prismatic colors. There are ten of these in the series, the object being to afford means for observation of the comparative absorbent powers of different colors for radiant heat. When exposed side by side to a common radiant source, as for instance in the direct rays of the sun, these instruments all disagree; while, if removed from the light and placed in an apartment of uniform temperature, their indications presently return to exact coincidence.

One of the most recently invented thermometric instruments, and one

as curious as it is likely to be useful, Casella's mercurial minimum thermometer, was not exposed. This instrument, which is the invention of Mr. L. Casella, maker of scientific instruments to the British admiralty, is as yet the only serviceable mercurial minimum thermometer, and the only minimum thermometer of any kind which is not in practice liable to troublesome derangements. As the maximum thermometers in common use are mercurial thermometers also, there is the additional advantage resulting from the employment of this instrument that both extremes of temperature are registered under the same conditions. There is no steel or other solid index subject to become entangled in the mercury contained in the tube; and the annoyance which, in the common minimum thermometer, so often arises from the sluggishness, evaporation, or breaking of the liquid column, is entirely avoided. The general form is shown in Fig.

Fig. 108.



Casella's Mercurial Minimum Thermometer.

108; *d* being a tube with large bore, at the end of which a flat glass diaphragm is formed by the abrupt junction of the small chamber *a b*, the inlet to which at *b* is larger than the bore of the indicating tube. The result of this is that, having set the thermometer, the contracting force of the mercury in cooling withdraws the fluid in the indicating stem only, while, on its expanding with heat, the long column does not move, the increased bulk of mercury finding an easier passage through the larger bore into the small pear-shaped chamber attached.

In arranging the instrument for use it is to be placed in a horizontal position, with the back plate *e* suspended on a nail, and the lower part supported on a hook, *f*. The bulb end may now be raised or lowered, causing the mercury to flow slowly until the bent part *d* is full and the chamber *a b* quite empty. At this point the flow of mercury in the long stem of the tube is arrested by adhesion to the diaphragm *b*, and indicates the exact temperature of the bulb, or air, at the time. On an increase of heat the mercury will expand into the small chamber *a b*; and a return of cold will cause its recession from this chamber only, until it reaches the diaphragm *b*, to which it adheres. Any further diminution of heat withdraws the mercury down the bore to whatever degree the cold may attain, where it remains until further withdrawn by increased cold, or till reset for future observation. When out of use,

or after transit, it may be that raising the bulb may not at first cause the mercury to flow from the small chamber as above; in such case a slight tap or jerk with the hand on the opposite end with the bulb up, will readily cause it to do so.

This ingenious instrument has been tested in use by Sir Henry James, director of the ordnance survey of Great Britain, by Mr. Stewart, director of the observatory at Kew, by Dr. Thompson, vice-president of the British Meteorological Society, and by many other distinguished observers, by all of whom it has been very highly commended.

PYROMETERS.

A trustworthy means of determining with accuracy the high temperatures of furnaces, or any elevated temperature exceeding that of boiling mercury, has not as yet, perhaps, been successfully secured. The earliest pyrometer which actually came into use was that of Wedgewood, invented about 1780. The principle on which this invention was founded is the well-known property of clay to contract under the action of heat. In form, the pyrometer of Wedgewood was extremely simple. It consisted merely of a gauge for measuring the dimensions of certain little clay cylinders before and after their subjection to the heat of the furnace. The test was in itself a very rude one, but the uncertainty of the indications of the instrument was increased by the fact, subsequently discovered, that clay may contract under the influence of a comparatively low temperature, long continued, to as great a degree as under a higher of less duration.

It was proposed, at about the same time with the origination of Wedgewood's invention, to construct a thermometer for high temperatures on the plan of the mercurial thermometer, employing a fusible alloy instead of mercury, and a tube of clay enamel, or translucent porcelain, instead of glass. This was the conception of Achard, and it has a *prima facie* plausibility in its favor; but it is not known to have been reduced to practice. In fact, considering the liability of the porcelain to contract in the furnace—the property from which the pyrometer of Wedgewood derives all that it has of practical utility—the indications of the high-temperature thermometer here proposed would be liable to uncertainty in a very high degree. Several very distinguished physicists have endeavored to reach a more satisfactory solution of this difficult practical problem by availing themselves of the expansibility of air under high temperatures. These efforts have been to a certain degree successful; but the methods to which they have conducted depend for their accuracy upon the truth of the assumption, not yetfully established, that the expansibility of gases at the highest artificial temperatures follows the same law as at those at which this law has been experimentally verified.

One of the most promising methods of pyrometric measurement which has yet been proposed is the suggestion of Professor Edmond Becquerel, of Geneva, and is founded on the principles of thermo-electricity. In

the Exposition of 1867, Mr. Ruhmkorff, of Paris, exhibits a thermo-electric pyrometer constructed under the direction of Professor Becquerel, which, in the experimental trials to which it has been subjected, has furnished indications remarkably consistent with each other; while it is free from complication of parts and apparently capable of being made practically available for all the uses for which such an instrument is needed. The thermo-electric combination employed by Mr. Becquerel is a single couple formed of two equal wires of platinum and palladium, each being one millimeter in diameter and two meters in length, united by one extremity in a junction formed by binding them firmly together with a fine platinum wire. The two elements, which are placed parallel to each other, are in contact to the extent of about one centimeter at the junction. In order to keep them separate for the rest of their length, the palladium wire is passed through a tube of porcelain; and this tube, with the two wires, is subsequently introduced into a larger tube of the same material, which last is to be exposed to the heat of the furnace. Both tubes are then filled with sand. The two wires are suitably connected at their outer extremities with the binding screws of a Weber's galvanometer, which indicates electric intensities with great exactness. A scale of temperatures related to the intensities of the developed currents has been prepared by Mr. Becquerel, by comparing the indications of an air pyrometer with those of the electric pyrometer when both are similarly exposed side by side. The divisions of this scale are equivalent to ten degrees centigrade each.

It cannot yet be said, perhaps, of any form of pyrometer, unless of that of Wedgewood, which, as we have seen, is untrustworthy, and which at best indicates differences of temperature very imperfectly, that its use for practical purposes is entirely unattended with inconvenience; but the electric pyrometer of Mr. Becquerel seems to come as near to fulfilling this condition as any that has yet been suggested.

V.—LIGHT.

If the exposition in the department of optics were to be judged by the degree to which it gave evidence of recent progress in scientific discovery, there would be some reason to feel disappointment with the results. Since the invention of the spectroscope no new optical instrument has made its appearance designed as an aid to investigation in any field entirely new. On the other hand, the variety and beauty of the familiar optical instruments exhibited, their superior and often exquisite workmanship, and the numerous improvements, many of them of importance, which were apparent in the details of their construction, gave to the exhibition an interest which, to some degree, compensated for the lack of novelty, and could not fail to impress the observer with a very high admiration of the accurate scientific knowledge and marvellous skill of their accomplished constructors. In this field France presented by far the most brilliant display. England would have been placed next in rank by one

who judged only according to the impressions produced upon the eye. A critical inquirer would, however, doubtless have pronounced that substantial merit was not distributed in proportion to the number or splendor of the objects exhibited; and such a critic would have found much to admire in the less showy but by no means less interesting exhibitions of Switzerland, Bavaria, Prussia, and Austria. The United States were among the nations least conspicuous in this competition, only one or two of our accomplished opticians having entered the field at all, and they in a form so modest that their contributions probably escaped the general eye.

OPTICAL GLASS.

To a person unacquainted with the peculiar difficulties which have impeded the progress of improvement of optical instruments of the highest order, it usually occasions some surprise to be told that the most serious of all these has always been the imperfection of glass. This substance is one which is so far from betraying to ordinary observation the faults which make it useless to the optician, that the specimens which seem most brilliant are not seldom those which are in this respect most faulty. Two kinds of glass, crown and flint glass, are combined in the construction of achromatic lenses. Crown glass is a compound of silex, potash, and lime. In the composition of flint glass one important constituent is the oxide of lead. Flint-glass is not so much a double silicate of alkali and lead as a mechanical mixture of two silicates. The unequal density of these two substances prevents their forming, while in a state of fusion, a mass of uniform character. The heavier of the two tends to sink to the bottom of the crucible, and the result is to produce a compound of very unequally refracting power. In the year 1824, a committee of the Royal Society of London, consisting of Mr. Faraday, Sir John Herschel, and Mr. George Dollond, was appointed to conduct an experimental inquiry into the processes of this manufacture, with a view to devise means of overcoming the difficulty here spoken of. The results of this investigation were communicated to the society by Mr. Faraday in 1829; but, though in many respects interesting, they served very little to advance the practical object in view. At this period the largest telescopic objective of satisfactory performance which the English opticians found it in their power to produce, did not exceed some five or six inches in diameter. A simple melter in a glass manufactory at Soleure, in Switzerland, by name Guinand, had previously to this, demonstrated the possibility of exceeding these moderate dimensions; but he made a secret of his process, and died in 1823 without having disclosed it. He became, however, early associated with the celebrated Fraunhöfer, and for some years furnished the material for the objectives which made the establishment of Utschneider and Reichenbach at Munich so deservedly renowned. Though his method of proceeding was never published by himself, it continued to be practiced by his son, and

it is still pursued by Mr. Feil, of Paris, a lineal descendant of Guinand, who presented in the Exposition of 1867 the most brilliant display of optical glasses which appeared there from any country. The nature of the process of manufacture is now substantially known. It consists in uniting numerous small selected masses of glass of ascertained equality of density and uniformity of refracting power, into one large mass, by pressure while in a plastic condition. It is a process therefore analogous to that of the welding of iron.

Among the objects exhibited by Mr. Feil were several specimens of the silico-borate of lead, a kind of glass of great specific gravity which was first produced by Faraday in the course of the investigation above mentioned, and which was obtained by him with a mean refracting index as high as 1.8735. He gave it the name of "heavy glass," its specific gravity varying from 4.20 to 5.44. The refracting index of the specimens exhibited by Mr. Feil was somewhat less than that above stated, being only 1.727. Mr. Feil also exhibited a magnificent disk of flint-glass of a diameter of seventy-two centimetres, or over twenty-eight inches.

Very large disks were also exhibited by Messrs. Chance, of Birmingham, England, a firm which has been long distinguished for the excellence and the large dimensions of its optical glasses. In 1855 this establishment exhibited in the Exposition of that year a pair of disks, crown and flint, about an inch larger than that of Mr. Feil above mentioned. These were purchased for the observatory of Paris, but they have not as yet been mounted. Messrs. Chance exhibited also a magnificent Fresnel light-house lens, formed in rings or zones of grand dimensions.

The exposition of Merz, the celebrated constructor of astronomical instruments of Munich, embraced one object-glass seventeen inches in diameter, and another of ten inches.

Very beautiful unwrought specimens were exhibited by Daguet, of Switzerland, with polished facets serving to show their excellence of quality.

Besides these, Steinheil of Munich, Secretan of Paris, Voigtlander of Vienna, and others, exhibited object glasses less remarkable in size, but of very superior quality.

The great glass company of St. Gobain, Chauny and Cirey, ought not here to be overlooked, though they exhibited nothing in the class embracing optical instruments. This company manufactures glass plates upon the grandest scale. One of their plates exhibited was found, by actual measurement, to have the dimensions of nineteen feet and six inches by eleven feet. They exhibited also very fine disks designed for the mirrors of reflecting telescopes.

A very fine collection of plane glasses with parallel surfaces was exhibited by Messrs. Radiguet and Son of Paris. The sizes ranged from one inch to more than twelve inches square. There were also circular glasses of similar dimensions. Many of these glasses were colored, to serve as darkening glasses for reflecting instruments, or for purposes of experimental investigation.

The exhibition of prisms by many distinguished constructors was very beautiful. Very large right-angled prisms (four inches on a side) were shown by Hoffman of Paris, who also exhibited admirable prisms of rock crystal, suitable for the study of the fluorescent rays beyond the violet.

The prisms of Steinheil, of Munich, were remarkable for the perfection of their angles. The hollow prisms for experiments on transparent fluids by this constructor were formed of plates of plane glass united without cement, being made water-tight by the perfection and polish of their surfaces.

A collection of thirty-five equal and similar prisms formed of different materials, which had been employed in the investigations of Baille on refraction, was exhibited by Madame Bertaud, of Paris, who also exhibited Silbermann's prism of variable angle for fluids, intended to facilitate the illustration of the laws of refraction in presence of large assemblies. The axis of this prism is horizontal. The ray of light to be experimented on is thrown vertically downward, and the refracting angle is that which is formed between the surface of the contained liquid and one of the inclined sides. By turning the prism around a horizontal axis of motion, the refracting angle is varied at pleasure, since the upper surface always remains horizontal. This construction facilitates the illustration of the variation of refractive power with density, which is accomplished by introducing into the liquid, during the progress of the experiment, various soluble salts.

TÖPLER'S STRIÆ DETECTOR.

In connection with this cursory notice of the optical glasses exhibited in the Exposition, it is proper to mention an ingenious apparatus invented by Professor Töpler, of Riga, (Russia,) and exposed by Mr. Wesselhoft, for detecting the faults of such glasses when they arise from irregularities of density. Such faults are in the nature of striæ, or transparent streaks, and are sometimes so gross as to be immediately perceptible by the unaided eye. But even when they are sufficiently slight to escape detection by any ordinary or simple method of observation, they are often still serious enough to render the glass in which they occur unfit for the more important uses of optics, as, for instance, for the construction of telescopes.

The apparatus of Professor Töpler embraces, first, a source of light, which is furnished by a lamp having before it an opaque disk provided with apertures of different dimensions which can be successively brought in front of the blaze, thus enabling the observer to vary the size of the radiant at pleasure. The light of this source falls upon a large lens of short focus, which produces a luminous image of it on the opposite side. If the observer place his eye immediately behind this image, he will see the lens uniformly illuminated. In this state of things a small opaque disk introduced exactly at the focal point and equal to the focal image, will eclipse the lens entirely. But this eclipse will not

completely take place unless the lens is free from all imperfections producing irregular refraction. If such irregularities exist, they will cause certain rays to deviate from the focal point in which the light is chiefly concentrated, and will produce an image of their figure, apparently traced more or less brightly upon a dark ground. The observation is facilitated by employing a telescope to assist the eye.

Töpler's striæ apparatus may, therefore, be described as being made up of the luminous source, the condensing lens, and the telescope. This last is called the analyzer. A large photographic lens of good quality serves very well for the condenser. This must be without imperfections of its own. Then, if an object glass, designed for a telescope or other purpose, is to be examined, it is placed, in general, as near as possible to the condenser, and on the side of the analyzer. The two lenses thus combined may be regarded as practically forming one. To the analyzer is attached the eclipsing apparatus, which is interposed after the adjustments are completed. The occurrence of a complete eclipse will be evidence of the good character of the glass under observation. The delicacy of this apparatus is such that Professor Töpler has successfully employed it in investigating the influence exercised upon the refracting power of solid bodies by pressure, or by variations of temperature; and in the atmosphere, by sound waves and other disturbing causes.

POLARIZATION.

While in the apparatus for experiment and research on the double refraction and polarization of light, many things were exhibited which were at once very interesting and very beautiful, there was scarcely anything present which could be said to mark decided progress in recent years. The exposition of doubly refracting crystals, cut for the display of their characteristic systems of colored rings and fringes, was very full and admirable. This was especially true of the collection of Hoffmann, of Paris, who, in this speciality, is without a rival. Duboscq, Bertaud, and Soleil also exhibited a great variety of interesting objects and articles of apparatus belonging to this department of optics. Mr. Soleil is the son of the highly distinguished optician and physicist, whose labors early contributed so much to the advancement of practical investigation in the higher optics, and who originated the very ingenious saccharimeter which bears his name. The son, who inherits much of his father's ability, has recently laid before the Academy of Sciences a description of an original method of obtaining plates of rock crystal with planes parallel to the axis, or of determining the error of parallelism, which was rewarded by that body with an expression of their high approbation. Mr. Soleil presented plates illustrative of his method, and enabled the jury to test the character and value of the indications by means of which his determinations are made.

HOFFMANN'S POLARIZATION MICROSCOPE.

In the collection of Hoffmann was embraced a large variety of tour-

malines of all sizes and colors. By the happy combination of these, he succeeds in obtaining polarized light very nearly or quite colorless; and he thus, in some of his instruments for investigation, has been able to substitute tourmalines instead of calcite prisms, with the advantage of a largely increased field of view. He exhibited, for instance, a polarization microscope, designed to show the colored rings seen in doubly refracting crystals cut across the axis, which for this purpose is superior to any polariscope or other combination of apparatus heretofore constructed. The instrument is at the same time very much more compact than the arrangements of Biot, Amici, Norremberg, or any others. These advantages are secured by employing an achromatized tourmaline as the polarizer. The inconveniences of polarization by reflection are thus avoided, and it becomes possible to observe with artificial light as well as with the natural. The parts of this microscope are, first, a concave mirror for collecting light, made of glass coated with platinum by Dodé's process—this metal being preferred to silver on account of its inalterability; secondly, a combination of four lenses forming the objective; thirdly, a combination of three lenses forming the ocular; and fourthly, a Nicol's prism as an analyzer, with a divided circle. The crystal to be examined is supported on the stage in a manner which permits a free motion of revolution, and also a change of position laterally. A number of accessories accompany the instrument, and add to its usefulness. There are, for instance, mono-chromatic glasses, by the interposition of which the rings or fringes observed will be exhibited with increased sharpness of definition, and in greater number; also mica plates of half or quarter of a wave value, quartz plates cut parallel and perpendicular to the axis, &c., &c., to be used in studying the disposition of the colors, the positive or negative character of the crystal, the direction of rotatory polarization, and other interesting properties. The instrument is further furnished with a provision for revolving the analyzer and polarizer at the same time, to demonstrate that while the curves or lemniscates of biaxial crystals revolve, the line which joins the centers of the two systems of rings preserves its position. The field of view of this instrument is so large that it shows not only both systems of rings in topaz, which in this crystal are separated one hundred and twenty-one degrees, but also even those of hyposulphite of soda, which are the most widely separated of any known. When applied to the measurements of angles exceeding one hundred and thirty-five degrees, the crystal under observation is immersed in a bath of oil, (olive oil bleached in the sunlight,) sulphide of carbon, or other highly refracting liquid. The trough should be made of thin glass, and should have a plane bottom of uniform thickness. The crystal is held in the liquid in a pair of tweezers. It is a great recommendation of this instrument that it admits of easy transformation into an ordinary polariscope, and is adapted to a larger variety of applications than any instrument of its class hitherto constructed.

THE HOFFMANN-WILD SACCHARIMETER.

Another interesting instrument exhibited by Mr. Hoffmann is the saccharimeter or "polaristrobometer," of which the original idea was suggested by Professor Wild, of Berne. This instrument, besides possessing great sensibility, is very sharp in its indications. The indicator is a polariscope of Savart, formed of two plates of quartz cut oblique to the axis and crossed upon each other, which exhibit parallel fringes with a central band, white or black, according as the polarizer and analyzer are coincident or crossed. The polarizer and analyzer in this instrument are both Nicol's prisms. The analyzing prism, which has a motion of rotation, is furnished with a divided circle. The observation is made by means of a small telescope, in which are stretched cross-lines inclined forty-five degrees to the vertical in the field of view. Between the indicator and the polarizer is placed the tube containing the solution to be observed.

The mode of observation is as follows: First, for adjustment. In the day time, the instrument may be directed towards a white cloud, or towards a white wall or screen. At night, it may be turned directly toward a lamp. It is desirable to bring the polarizer and analyzer into such a position, relatively, that the field of view may present a white stripe upon the center of the cross, bordered by two dark stripes. This adjustment having been made, it is to be noticed what is the index error; and as the analyzer is capable of being turned round in its circle, it is turned by the amount of the error, so that when the zero of the circle is brought to the fixed index, the appearance just described may be present. The tube containing the liquid to be examined is then introduced; and this, if possessing the property of rotatory polarization, will turn the plane of polarization of the incident light to the right or the left, so as to extinguish the white band in the middle of the field, and cause it to be replaced by one more or less dark, and bordered by colored fringes. A corresponding rotation of the analyzer will restore the central white band, and the number of degrees necessary for this restoration will be read off on the circle. The direction in which it has been necessary to turn the analyzer will determine whether the rotatory power of the liquid is positive or negative. It is stated that the instrument is accurate to the tenth of a degree, at least for angular movements below five degrees. For larger rotations a severer accuracy will be obtained by employing mono-chromatic light; as, for instance, the soda flame obtained by burning an alcoholic solution of salt. Practically the same result may be obtained in compound light by interposing between the eye and the analyzer a disk of red glass.

THE HARTNACK-PRAZMOWSKI POLARIZATION PRISM.

While speaking of the exposition of matters relating to polarization, the new calcite polarization prism of Hartnack and Prazmowski ought not to be overlooked. This prism, introduced by Hartnack for use in

his microscopes, but capable equally of general application, is constructed, like the prism of Nicol, on the principle of suppressing the ordinary ray by internal reflection. In the prism of Nicol there is first formed an oblique rhombic prism, with lateral edges exceeding the terminal as three to one, by dividing the original crystal according to its natural cleavages. A diagonal section is then made of this prism, in such a manner as to divide it symmetrically, from one of the obtuse angles to the other; and the separated segments are re-united by a cement of Canada balsam. In the Hartnack-Prazmowski prism, after the original crystal has been prepared as above, only with lateral dimensions proportionally greater by rather more than one-third, the ends are truncated by planes inclined about twenty-eight degrees to the optic axis, and on these planes as bases is constructed a rectangular prism, which is afterward sawn asunder in a diagonal section conjugate to the optic axis, or coincident with what may be called the optic equator. This construction increases the field of view about one-third—a very sensible advantage to the observer, especially in microscopic observation; but it cuts the natural crystal to a greater disadvantage than the method of Nicol. In re-uniting the sundered portions of the prism, Mr. Hartnack uses drying oil (linseed) as a cement, by preference to Canada balsam; the index of refraction for this oil corresponding very closely with that of the extraordinary ray. In regard to the absolute ultimate relations of length and breadth in this prism and in that of Nicol there is no material difference; but the rectangular form is a great advantage.

The most compact form of calcite polarization prism by far is that of Foucault, in which the separated segments, after being polished on the surfaces of the section, are re-united without a cement, a film of air only intervening between the surfaces in juxtaposition. Unfortunately, the ordinary ray is not totally reflected by this prism, unless the rays of the incident beam are parallel. When used with divergent or convergent rays its performance is very imperfect, and it is therefore not adapted to the uses of the microscope.

MISCELLANEOUS APPARATUS.

The apparatus devised by Mr. Jamin for measuring the difference of phase between the undulations of two rays was exhibited by the house of Madame Bertaud in a style of elegance amounting to luxury. The same house also exhibited the elaborately constructed instrument by means of which Mr. Cornu has conducted his interesting investigations of the reflection of crystalline surfaces.

The exposition of Mr. Soleil embraced also Fizeau's apparatus for measuring the expansion of crystals in different directions under the influence of heat. The crystal, reduced to the form of a plate with parallel surfaces, rests upon the curved surface of a plano-convex lens of glass having a large radius of curvature, and presents to the observer who views the point of contact from above, the colored rings of Newton. As the crystal expands, these rings undergo apparent changes of diame-

ter, and the measurement of these changes which the apparatus is designed to effect furnishes the data for deducing the law of relative expansion.

PHOSPHORESCENCE.

Preparations of phosphorescent material, which, on being viewed in darkness after a brief exposure to the sun, appear brilliantly luminous and exhibit the most superb tints, have been in recent years very considerably multiplied. These were beautifully illustrated in the expositions of Alvergniat Brothers, Mr. L. A. Gaiffe, and perhaps others. The simplest form in which the preparations are displayed is to introduce them into glass tubes, which are afterwards hermetically sealed. A series of such tubes is arranged side by side in a dark box. After exposure the box is carried into a dark room and opened, when there bursts forth a glow of varied and rich tints, which to a spectator unprepared for the surprise is truly dazzling. These phosphorescent powders were, however, managed by the ingenious exhibitors so as to produce effects still more striking than this. Upon a dead-black surface they had been spread out in thin layers, so as to form images of familiar objects in their natural, but more than naturally brilliant, colors. A thin coating of paraffine secures their adhesion, without in any manner injuring their phosphorescent properties. Butterflies, ornamental stars, and other fanciful images were thus prepared, the powders being laid on according to the tints they are capable of producing, as a painter lays his colors upon a picture. Before exposure to the sun the whole image is of a dull and uninteresting uniformity of gray-white tint, but the first touch of the sun's rays kindles it into beauty. One of the most striking objects of this class exhibited by Mr. Gaiffe was a representation of the solar spectrum. The spectator could hardly persuade himself that it was not the real object.

SPECTROSCOPES.

The principal exhibitor of spectroscopes was Mr. Duboscq, of Paris. This exhibitor presented a variety of models, with prisms varying in number from one to six. The six-prism spectroscope of Mr. Duboscq is so constructed as to permit the use of all the prisms at once, or of one or two only; the observing telescope meantime retaining its place. The telescope receives two motions of adjustment, one vertical and the other horizontal; and also a lateral micrometric movement for ranging along the spectrum. The same exhibitor showed also the pocket spectroscope of Amici, in which the light, after refraction by a single prism, is brought back to the direction of incidence, without being affected as it respects dispersion, by total interior reflection from one of the surfaces of a second prism of suitable form. A spectroscope exhibited by Brunner, on the plan of Jamin, capable of being used also as a goniometer, and having a divided circle of twelve inches in diameter, was one of the finest instruments of its class in the Exposition.

The most convenient form of spectroscope for ordinary uses is the direct-vision spectroscope, in which the dispersion is effected by prisms contained within the tube of the observing telescope itself, as in the case of Amici's pocket spectroscope mentioned above. The Abbé Moigno, in his journal Les Mondes, states that Jansen was the first to design a spectroscope in this form, which seems not to have essentially differed in principle from that of Amici, but which was considerably more powerful. In the instrument of Amici the ray, after having been dispersed by one prism, is brought by reflection into its original direction, the dispersion remaining. In Jansen's, a second pair of prisms is placed immediately behind the first, which is in all respects similar to that. The effect is therefore to double the dispersion.

A form of the instrument superior to either of these has been contrived by Hoffmann, of Paris, the very able constructor to whose skill the investigators of the higher optics have been so much indebted, and who has furnished to Father Secchi and to Mr. Huggins the instruments which have enabled them to prosecute so successfully the spectral analysis of stellar and nebular light. In Mr. Hoffmann's direct-vision spectroscope, the apparatus for dispersion consists of five prisms, three of crown glass and two of flint glass, cemented together into one system with their refracting angles alternately in opposite directions. The arrangement resembles that of the group of letters AVAVA, in which the cross-line of the letters A indicates the path of the light through the system. The dispersion is differential, the angles of the prisms being so chosen as to compensate the mean refraction; and the mean ray emerges parallel to the direction of incidence. But as the extreme rays of the spectrum produced by the dispersion are necessarily not parallel to the same direction, the tube is jointed at a point just behind the system of prisms, and the part near the eye has a liberty of lateral motion sufficient to enable the observer to bring any portion of the spectrum into the field of vision. The angles actually given to the several prisms at their summits are ninety degrees for the two flint-glass prisms, represented in the group of letters above by the two V's, and also for the central prism of crown glass. The angles of the extreme crown-glass prisms are only sixty-nine degrees.

It is obvious that by increasing the number of prisms a larger dispersion might be obtained; but this would render the instrument more cumbrous, and would diminish the intensity of the illumination. The system of prisms occupies of course a position in the tube immediately in front of the objective of the telescope. But in front of the system itself is another lens designed to render the rays parallel as they fall on the prisms; and the tube, which is extended beyond this lens, carries at its extremity the variable aperture through which the narrow beam of light to be observed is admitted. In order to compare this light with that coming from a different source, a small reflecting prism is placed in front of the opening which it covers only in part, and which is sustained by a support fastened to the tube by a ring clamp. A micrometer very

finely divided on glass is introduced into the field of view within the instrument, by means of which the observer may measure the distances between the spectral lines.

Before leaving the subject of the spectroscope, mention must be made of the extended and beautifully clear photograph of the spectrum exhibited in the United States section by Mr. Lewis M. Rutherfurd, of New York, which excited great interest and attracted very general admiration. It was the only object of its kind in the Exposition.

The same gentleman also exhibited a photographic view of the moon on a very large scale, (twenty-one inches in diameter,) which for sharpness of delineation of the features of that remarkable body, may justly be pronounced the very best representation of the object which has yet been obtained. In making this remark the admirable photographs of the same body by Dr. Henry Draper, of New York city, and by Mr. Warren De la Rue, of London, are not forgotten. These very beautiful objects, for which a silver medal was awarded to Mr. Rutherfurd, have been presented by him to the *Conservatoire des Arts et Métiers*, of Paris.

TELESCOPES.

Mention has already been made of the telescopic objectives sent to the Exposition by many distinguished constructors. The number of telescopes of large dimensions present, fully mounted for use, was not large. It was hardly to be expected that it should be, considering the costliness of these instruments and the risk attending their transportation to distances. The most beautiful object of this kind was an equatorial by Dallmeyer, of London. This also presented some novelties in the details of its mounting. The instrument is provided with two independent hour circles, driven by the same mechanism, one of which gives the right ascension of the object observed, and the other, which is under the eye of the observer, the sidereal time. Adjustment in right ascension can be effected, to a certain extent, without interfering with the action of the driving power, by a movement of the tangent screw in the direction of its length.

In the Russian section, Mr. G. Brauer, of St. Petersburg, exhibited a transit instrument in which the eye piece is situated in the axis of rotation. A reflecting prism placed in the middle point of this axis receives the light from the objective and deflects it at right angles to its original direction. The advantage of this arrangement consists in the fact that the position of the observer remains unchanged, whatever be the position of the telescope, and that he looks always in a horizontal, that is to say, a convenient, direction. Whether there may not be some compensating disadvantages, remains to be tested.

Astronomical telescopes of merit were exhibited by Mr. P. G. Bardou, and Mr. N. E. Evrard, of Paris, each of these having a clear aperture of ten inches in diameter. Mr. Bardou presented, in addition to this, a truly splendid collection of terrestrial telescopes of very various sizes, and different styles of mounting. Many of the larger forms were mounted

in aluminium, with the advantage of great reduction in weight. Observation with these instruments is attended with greatly diminished fatigue, when they are compared with others mounted as usual in brass.

A rather curious telescopic instrument was exhibited by Mr. H. Ausfeld, in the Prussian section, called Zollner's Astrophotometer, a name which explains itself. The design is to measure the *brightness* of the stars by comparing them with an artificial star of standard brightness. The telescope is directed to the natural star, and the light of the artificial star is introduced through a lateral tube. A petroleum lamp serves for this object, the lateral tube carrying a diaphragm with a minute perforation in the center. In the interior of the principal tube, a plane glass mirror with parallel surfaces, placed at an angle of forty-five degrees, reflects the light of the artificial star to the eye; and as the mirror has a sensible thickness, two images are perceived with a small space intervening between them. The image of the natural star is brought to occupy this intermediate space. The lateral tube contains a polarization apparatus, by means of which the light of the artificial star may be modified both for color and for brilliancy. The first adjustment is for color. By rotating the polarization system the tint which corresponds to that of the real star observed is easily obtained, as in the saccharimeter. Then by turning one of the prisms of the system, the brightness of the artificial star, which is always at first superior to that of the real object, is gradually subdued until the two intensities are sensibly equal. As the image reflected from the first surface of the mirror is necessarily the brighter of the two, this one is selected as the standard of comparison. The other serves as a lower limit, and between the two the determination can be very accurately made.

A compact pocket telescope was exhibited by Mr. Hoffman, which seems to be very well adapted to the uses of army officers, explorers, and travelers, being without a draw; and yet, though only five or six inches in actual length, having a real focal length nearly three times as great. This paradoxical effect is produced by the introduction into the body of the instrument of two equilateral right-angled glass prisms, by means of which the light of the objective is made to traverse a space nearly three times the length of the instrument, in passing from the objective to the ocular. One of these prisms, at the end next the observer, receives the light from the objective perpendicularly upon the hypothenuse, and, by two successive internal and total reflections, sends it back toward the object. The second prism receives in like manner the returning rays, and, by a second similar double reflection, sends them back once more in their original direction to the eye. This telescope, as the Abbé Moigno asserts, was selected by the Emperor on the eve of the campaign of 1856, in Italy, for his personal use; and "was made the inseparable companion of his glorious expedition."

Opera and marine glasses were exhibited in large numbers, by many constructors. Among instruments of this description, was one designed

for the pocket, by Mr. A. Rieder, of Paris, in which the lenses were hinged in such a manner as to fold down flat. In this form the instrument is very convenient for travelers or sight-seekers, to whom, in its ordinary form, it is often an incumbrance. It appeared to be well constructed, and not liable to derangement.

Among the accessories to the telescope deserving notice in the Exposition, may be mentioned the substitutes for the spider lines of micrometers, exhibited by Breithaupt & Son, of Hesse-Cassel. These constructors employ for this purpose lines ruled with a diamond point, on plates of thin glass. There is no objection to such micrometers, unless it be the loss of light occasioned by the introduction of additional reflecting surfaces; while the advantage resulting from their inalterability of position is very great. Spider lines may become displaced, or they may be relaxed in consequence of the varying hygrometric state of the air; while the plates, unless broken, an accident to which in their protected situation they are not liable, are subject to no sensible change. And even in case of a fracture, a reserve plate may be introduced with very trivial loss of time; while the reconstruction of the spider-line micrometer is a troublesome task.

The isochronal regulator of Foucault is another of these accessories, which is as admirable in its performance as useful in its results. This was illustrated in a striking piece of mechanism exhibited by Eichens, of Paris, and constructed by him as the driving apparatus of an equatorial telescope designed for the observatory of Lima, in Peru. The resistance to acceleration in this contrivance is furnished by two wind-vanes attached to the outer angles of a jointed parallelogram, which is carried by a spindle forming the axis of the last wheel of the train. Between this variable fly and the driving weight, there is such a connection that each opposes the variation of the other so efficiently as to leave the resulting velocity strictly constant. The machine may be said, indeed, to be very slightly over-corrected; for when the driving weight is largely varied, reduced, for example, by one-half, or increased by one-half, there is a trivial increase of velocity with the minimum weight. But for any fluctuations of resistance to motion likely to occur under the conditions in which the machine is to be used, the variation is practically insensible.

Reflecting telescopes were illustrated in the Exposition only by a single example. Mr. Secretan, of Paris, exhibited a telescope of this description, with a silvered glass speculum; but its dimensions were quite moderate, only slightly exceeding six inches in diameter. The same constructor has, however, produced other telescopes of the same kind of much larger dimensions; one of which, constructed for the observatory of Marseilles, has a diameter exceeding two feet and a half. In our own country, we have a very fine example of such an instrument, in the silvered-glass reflecting telescope, constructed by Dr. Henry Draper, of New York, and described by him in the 14th volume of the Smithsonian

Contributions to Knowledge. The substitution of silvered glass for speculum metal in this class of astronomical instruments was originally suggested by Mr. Foucault, and the resulting advantages are very great. The specific gravity of glass is two or three times less than that of metal; and besides this, from its great rigidity, the same thickness is not required in a glass mirror which is indispensable in the heavier material. Glass is also much more easily wrought than metal; and the loss of light from polished silver is but an inconsiderable fraction of the whole, while the loss from the surface of a metallic mirror is from one-third to one-half. And it is an important consideration that, if from any cause the silvered surface of the glass mirror should lose its brightness, the entire coating can be easily removed by solution and replaced by another, without the necessity of grinding anew. For these reasons it is probable that the reflecting telescope will hereafter come into more general favor than has been hitherto the case.

MICROSCOPES.

In no branch of physical investigation has the number of zealous devotees in recent years more rapidly increased than in the study of microscopic organisms. And no instrument of optics has occupied in its construction a larger amount of practical skill of the highest order, or has received more numerous and more important improvements, whether in its optical or its mechanical parts, during the same time, than the microscope itself. It is, indeed, the high perfection and wonderful power of this instrument as at present constructed, which, by affording clear and satisfactory views of the structure of objects only recently esteemed excessively difficult and doubtful, and by thus immensely diminishing the labor of microscopical research, has given to it its present great and rapidly increasing popularity.

The modern microscope may be said to date from the year 1829, the date of the publication by Mr. J. J. Lister of his well-known empirically discovered laws governing the aberrations of lenses, and the practical methods deduced from them of balancing these aberrations in a system of lenses against each other. The combinations of glasses, which had been previously most satisfactory in their performance, in the objectives of Chevalier and other eminent opticians, had been rather the result of patient experiment or happy accident, than of any antecedent calculation founded upon established principles. And the investigations of the earlier microscopic inquirers, such as Leeuwenhoeck, Swammerdam and others, had been conducted almost wholly by means of single lenses. In the time of these distinguished investigators, indeed, the compound microscope was esteemed, and not without reason, as comparatively untrustworthy; and the difficulties under which they prosecuted their researches were so great, as to make the recorded results they left behind them seem, at the present day, for their general accuracy, to have been almost miraculous achievements.

The effect of the introduction of Mr. Lister's improvements was immediately to throw nearly the whole class of what had been called *test objects*, into the category of common objects; but it created a new set of tests, or a new succession of tests, of constantly increasing difficulty; and in the active rivalry which has grown up between the many accomplished opticians of recent years who have devoted themselves to the improvement of this instrument, the chief contest has been, which should most satisfactorily resolve the most difficult of these tests. The tests themselves here spoken of are, in general, certain exceedingly fine markings which exist upon the minuter natural objects. For the more important uses of the microscope, the resolution of these markings cannot be said to be essential; but inasmuch as to resolve them implies in the microscope a power of definition carried to the last degree of perfection, the effect of this contest has been undoubtedly greatly to improve the instrument for all other purposes. For though the objectives of highest resolving power are not those which are most serviceable for the ordinary uses of the botanist, the mineralogist, or the physiologist, they involve, nevertheless, all the difficulties of construction which attend the latter, and others besides, so that their improvement implies a corresponding improvement of the whole series.

The expedients by which the resolving power of microscopic objectives is exalted are principally two, the shortening of the virtual focal length of the system, and the enlargement of the angular aperture. By angular aperture is meant the angle formed at the front of the objective by lines drawn from its center in all directions, limiting the visibility of objects placed before it. This also is the angle of spread of the cone of rays proceeding from a given point in the object observed, which, falling on the nearest lens, are so refracted as to meet the eye.

The shortening of the focal distance has been progressively carried to a point at which nothing further can probably be done usefully in this direction. Messrs. Powell and Lealand, of London, whose absence from the Exposition was much regretted, have constructed objectives of great merit, having a virtual focal length of only one-fiftieth of an inch. Mr. Hartnack, of Paris, states the focal length of his highest number (No. 18) at less than half a millimeter, or one fifty-fifth of an inch. When it is considered that this is not the distance at which the object must be placed from the front glass of the instrument, but that this latter distance is materially less, not exceeding the $\frac{1}{100}$ or the $\frac{1}{200}$ of an inch, and that the objects to be observed are of such delicacy as to require to be protected by a covering of thin glass, it will be seen that the expedient here spoken of for improving the power of the instrument has been worked out to the last point of availability.

The same remark is equally true of the other. The angular aperture of microscopic objectives has been increased up to one hundred and seventy-eight degrees; but this increase, at least for the last fifteen or twenty degrees, is attended with no very perceptible gain of power,

since the extreme rays meet the front of the objective so obliquely that they are principally reflected and lost. In order to obviate in some measure this disadvantage, some constructors have given to the front surface of the foremost lens of the system a slight concavity; but the extent to which this modification can be carried is quite inadequate to afford any effectual remedy.

The constructors of microscopes whose instruments have been in highest repute since the introduction of Mr. Lister's improvements, have been, in England, Messrs. Smith, Beck & Beck, a house now only represented by Mr. J. Beck, nephew of Mr. Lister; Mr. Andrew Ross, who has been succeeded by Mr. T. Ross, his son; and Messrs. Powell & Lealand, already mentioned above; and in France, Mr. Oberhauser, who has given place to Mr. E. F. Hartnack, and Messrs. Nachet & Son, whose excellent instruments are well known in this country.

Of American constructors there are several whose objectives will bear severe comparison with those of the best foreign makers. The earliest among those to secure for our country a distinguished position in this honorable rivalry was Mr. Charles S. Spencer, of Canastota, New York. There was claimed for Mr. Spencer's microscopes, it is believed with justice, a decided superiority to any that had been previously constructed abroad in respect to resolving power; and they continue still to compare favorably with the best; but it is now some years since Mr. Spencer voluntarily abandoned a field in which he had won so distinguished laurels, and in the meantime there has been sensible improvement in the work of foreign makers. Fortunately, however, the retirement of Mr. Spencer did not leave our country unrepresented in this important branch of constructive art. A worthy successor to his skill and inheritor of his honors presently appeared in the person of Mr. Robert B. Tolles, also originally of Canastota, but at present the superintendent of the Boston Optical Works, whose objectives are unsurpassed in excellence by any in the world. Mr. William Wales, of Fort Lee, near New York, contests closely with Mr. Tolles the palm of superiority; and between these two accomplished constructors the microscopic world has not been able to pronounce a decision more favorable to one than to the other. Besides these, our country has a number of other constructors of excellent microscopes, among whom are pre-eminently entitled to be mentioned, Messrs. J. & W. Grunow, of New York, and Mr. J. Zentmayer, of Philadelphia.

Several important improvements in the form and accessories of the microscope have originated also in the United States. The stage indicator for finding minute objects with high powers, which since its suggestion has assumed a variety of forms in the hands of different constructors, was invented by the late Professor Bailey, of West Point, a gentleman to whom microscopic science is indebted for many valuable contributions; and the inverted microscope of Dr. J. Lawrence Smith, of Louisville, Kentucky, furnishes to the chemical investigator a most

important addition to his resources; preventing as it does the obscuration of the view by the condensation of vapors, and securing the instrument against injury from the action of corrosive fumes. Microscopists have also been much indebted to Professor Hamilton L. Smith, now of Hobart College, Geneva, New York, for various ingenious improvements of microscopic apparatus, among which may be mentioned his illuminator for opaque objects, in which the light is received upon a mirror within the tube behind the objective, through an aperture in the side, and is thrown down upon the object through the objective itself; his "mechanical finger," an instrument for picking up with facility and precision, upon the point of a hair, objects invisible to the naked eye, separating the different species when mixed, and arranging them conveniently for observation; and his binocular eye-piece, for use with high powers of the instrument, the only eye-piece of this kind which has as yet satisfactorily solved this difficult practical problem.

The number of microscopes present in the Exposition of 1867 was very great. It is a circumstance very strikingly evidencing the growing demand for instruments of this class that the business of constructing microscopes for ordinary use has recently developed itself into a regular manufacture. The consequence has been an immense reduction in prices; so that the possession of an instrument really useful and meritorious is no longer the exclusive privilege of persons of large means. In Paris, the house most remarkable for the cheapness of its microscopes, telescopes, and other optical apparatus, is that of Mr. Alexander Lebrun, Rue Chapon, No. 25. Mr. Lebrun has a very large manufactory at St. Pierre-les-Bitry, where the instruments are for the most part actually constructed. He furnishes a very neat, well-constructed microscope, with achromatic lenses superposed in the manner so familiar to those who have used the Chevalier microscopes, with two oculars, and a condensing lens for opaque objects, all compactly arranged in a substantial box, for fifty francs—say ten dollars. His models less complete in details range at lower prices down to four and a half francs, which is the price of a small microscope with a single objective and a single ocular. Mr. Lebrun's prices for portable telescopes, marine glasses, reading glasses, prisms and other optical apparatus, are similarly moderate. A pocket telescope, for instance, with a one-inch objective of sixteen inches focus, having a mahogany tube, and three draw-tubes of brass, is furnished at a cost of only five francs. And a larger instrument of the same kind, with an objective of 2.4 inches, focal length of four feet, and four draw-tubes, costs but fifty francs. It is not to be supposed that, because these prices are so low, the workmanship is inferior. On the other hand, these instruments are elegantly finished, the metal work is highly polished, the external tubes are varnished, rubbed down and similarly polished, and the optical performance admirable. With one of these little telescopes, the writer found no difficulty in reading the hour on the clock dial of the École Militaire, at a distance of nearly two miles.

In London, microscopes of very good quality are furnished at prices which approximate, as it respects cheapness, very nearly to those of Mr. Lebrun. A very good assortment of such will be found at the establishment of Mr. W. E. Statham, No. 111, Strand. Mr. Statham constructs a variety of patterns and sizes of "youth's" and "student's" microscopes, varying in price from half a guinea to about four pounds; but he also constructs the more expensive forms of stands, and the superior objectives on the Lister principle, for prices correspondingly greater.

In our own country, Messrs. Pike in New York have long been known as constructors of philosophical apparatus, from whom microscopes in every form may be obtained; and it is believed that this firm is able to supply instruments of this class of a popular character, on terms which will favorably compare with those offered by London makers.

Many admirable microscopic objectives constructed on the Lister principle were exhibited at the Exposition, chiefly by French, English, Swiss, and American makers. Some of those by Mr. E. F. Hartnack, of Paris, embraced a novel feature, called by him *double correction.* To understand this it is to be observed that the adjustment of the Lister combination, by which the aberrations of the several lenses of the system are balanced, is made on the supposition that the object to be viewed is placed before the objective without any intervening refracting medium except the air. But the preservation and security of the more delicate microscopic objects requires that they should be protected by a covering of thin glass; and this, although its thickness does not in general exceed $\frac{1}{100}$ of an inch, and is often much less, produces a new aberration, which confuses the image, and in the case of objectives of high power, utterly destroys the distinctness of definition. The principles which guided Mr. Lister in the original adjustment of the combination suggested to him a simple means of correcting this confusion, which consists in slightly increasing the distance between the front lens of the system and the two others behind it. The observer is enabled to make this correction for himself, by turning a milled ring near the front of the objective until the distinctness of the image is restored. There is a limit beyond which this correction cannot be carried; and if the thickness of cover is too great to be dealt with in this way, the attempt to observe must be abandoned. Mr. Hartnack's system of double correction consists in making the distance between the second and third of the lenses of the system variable, as well as that between the first and second. Both the movements required to produce this double effect are made simultaneously by means of the same ring; and the advantage which Mr. Hartnack claims for the improvement is that it permits the use of a thicker cover for the object observed.

The only other point of new interest which presented itself in the examination of the first-class objectives exhibited was found in the application by Messrs. Hartnack and Nachet to the construction of

their most recent lenses, of what is called the principle of immersion, a principle first suggested in 1855 by Professor Amici, of Florence, and actually reduced by him to practice at the time. This principle is applicable only to those powers which approach in use very closely to the object observed; and it consists in introducing between the objective and the covering glass of the object a drop of water in which the lens is immersed, to the exclusion of the intervening stratum of air. Although the great advantage obtainable by the use of this simple expedient was practically demonstrated by its originator twelve or fourteen years ago, in the superior performance of the objectives constructed by him with his own hands, the method was received with indifference or distrust by professional opticians, who continued by preference to construct all their objectives upon principles to which they had been long accustomed. Some three or four years ago Mr. Nachet revived the idea of Amici, and commenced the construction of immersion lenses, to the great improvement of his instruments. In this he was shortly afterward followed by Mr. Hartnack.

The great superiority in resolving power between the "wet" and the "dry-working" lenses was very manifest in the comparisons made at the Exposition. The result has been to induce many makers to adopt the Amici principle in their more recently constructed high-power objectives; and among these Messrs. Tolles and Wales, in this country, and Messrs. Powell and Lealand, of London, have been pre-eminently successful. It is not necessary for Americans any longer to go abroad in order to obtain microscopic glasses of any description of the highest order of excellence. The objectives of Messrs. Tolles and Wales, whether constructed for working wet or dry, will stand the severest comparison with those of the most successful constructors of England or France.

Another particular in respect to which there has been a material improvement in the recent forms of microscopic apparatus, consists in the adaptation of the instrument to binocular vision. The use of two eyes instead of one is attended with a very sensible relief to the observer, and tends to prevent the injury to the sight which may result from the unequal use of the organs. But there is, in a strictly scientific point of view, another and a very signal advantage gained by the use of the binocular form of the instrument, and this consists in the important aid to the judgment in regard to the real structure of microscopic objects, which is derived from the stereoscopic effect of binocular vision. It is unnecessary to add that not only is the comfort of the observer promoted by this mode of observation, but his pleasure in observing is also greatly enhanced by seeing objects in all their three dimensions, in their depth as well as in their length and breadth.

After the discovery of the true secret of binocular vision by Professor Wheatstone in 1838, but especially after the construction of the lenticular stereoscope by Sir David Brewster, in 1852, and its introduction

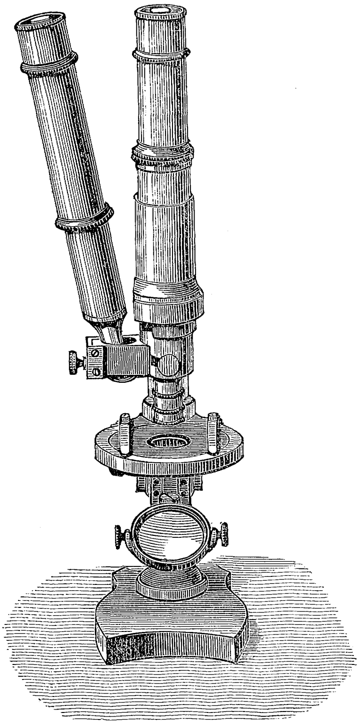
into general use, the thought of making this principle available in microscopic observation came naturally without doubt to many minds; but the first reduction of this thought to a practical form was made by the late Professor J. L. Riddell, of the University of Louisiana, in New Orleans. Professor Riddell employed a pair of small rectangular prisms, with their bases in a common plane and joined by the acute angles at the base, immediately behind the objective, to split the emergent pencil into two equal portions, which were reflected horizontally right and left. A second pair of similar prisms received these horizontal rays, and by a second reflection sent them in the direction of the observer. In this manner the rays which belong to the right half of the pencil reflected are conveyed to the right eye; and those which belong to the left half of the same pencil are conducted to the left eye. If, therefore, the rays were not crossed in the objective, that is to say, if the image were erect, the stereoscopic effect would be true; but as such a crossing does take place with an accompanying inversion and reversal of the image, the stereoscopic effect is reversed also, and becomes what is called pseudoscopic. The object is presented, indeed, in three dimensions, but its reliefs are depressions and its depressions are reliefs. Other forms of the apparatus, early suggested, were liable to the same objection. The earliest truly stereoscopic binocular microscope constructed appears to have been that of Mr. Nachet, in which an equilateral prism was employed to effect the separation of the pencil by internal reflection from the inclined sides, the light from the objective being received perpendicularly upon its base. Two other similar prisms by subsequent reflection directed the two halves into which the original pencil was thus divided to the eyes of the observer. These two halves, from the manner of their reflection in the first prism, necessarily crossed each other before emergence, and by this means the pseudoscopic effect which had attended the former constructions was prevented.

Theoretically, the binocular microscope of Mr. Nachet is unexceptionable; practically, it is difficult for many observers to make the two images coalesce. This seems to be owing to the fact that the two eye tubes are perfectly parallel, whereas it greatly facilitates the recognition of two images as belonging to the same object, to present them in such a manner that the axes of the eyes must be slightly inclined toward each other in order to receive them. For this reason in part, but more perhaps on account of the greater simplicity of construction, the well-known Wenham binocular, in which the division of the compound pencil is effected by means of a trapezoidal prism, has met with more general favor; and this form of the instrument has come extensively into use in England and in this country.

Mr. Nachet has recently introduced a binocular microscope of a much simpler description than his original one, which possesses the recommendation of being applicable to an ordinary instrument without altering its construction or interfering with its usefulness as a monocular.

An opening is simply made in the side of the body, immediately behind the objective, into which is introduced a rectangular prism carried in a mounting of metal, which reflects half the compound pencil horizontally, and this is received upon another prism which d rects it to the eye of the observer. The instrument, which is not particularly sightly, is represented in the figures annexed. Fig. 109 is a view of the instru ment with the parts united; Fig. 110 shows the principal parts separate, and illustrates the manner in which the dividing prism is introduced. In order to accommodate the two tubes to the varying distance between the eyes of different observers, the horizontal part containing the prisms was originally made with sliders; but in the form which was exhibited in the Exposition, the extra tube has an angular movement around its lower extremity as a centre. This involves the necessity of a corresponding movement of the reflecting prism at the centre of motion, to one-half the same angular extent. Mr. Nachet has contrived an ingenious and simple combination of levers by which both movements are produced in their due proportion on turning a single milled head.

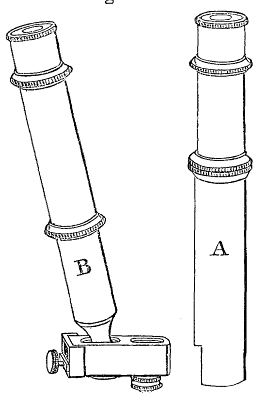
Fig. 109.



Nachet's Binocular Microscope.

This form of the binocular microscope is attended with an advantage peculiar to itself. It has been observed above that true stereoscopic vision requires that the two halves into which the compound pencil is divided behind the objective should cross each other, so that the right eye may receive the left-hand half and the left eye the right-hand half. The rectangular prism when introduced through the side of the body must therefore be advanced so far as to reflect the opposite half of the compound pencil, while it leaves the adjacent half free to pass. But if this prism, of which the position can be controlled by means of a slider, is drawn toward the extra tube so as to reflect the nearer half of the compound pencil and to allow the opposite half to pass freely, the conditions will be such as to produce pseudoscopic vision, and to present an image in which the reliefs shall appear as

Fig. 110.

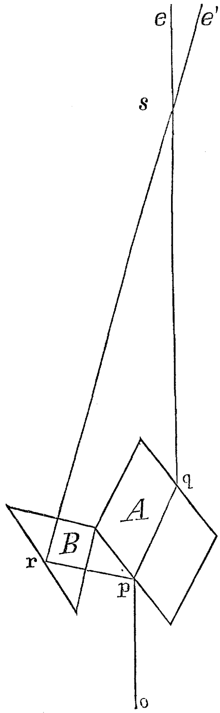


Parts separated.

depressions and the depressions as reliefs. In the examination of an object of obscure structure, the contrasts of appearance thus presented are often very serviceable in contributing to the formation of correct judgments.

It is a disadvantage common to all the forms of binocular microscope above mentioned that they perform well only with objectives of comparatively low power. In fact, it is obvious that a performance theoretically perfect would require not only that the division of the compound pencil emerging from the objective should be exactly equal, but that each of the simple pencils of which the compound pencil is made up should also be equally divided. Such an equality could only be perfectly secured by making the division in that plane or cross-section in which the axes of all the simple pencils cross, which would be really the plane passing through the centre of the front lens. At any distance behind this plane the simple pencils are more and more unequally divided, in proportion as they proceed from points more and more distant from the axis. And inasmuch as with the higher powers the cross dimensions of all the pencils are proportionally reduced, it follows that a division which must necessarily take place at some distance behind the innermost glass of the objective will become increasingly unequal as the power increases. A practical limit is therefore soon found to the availability of a binocular system in which the division is effected in the manner above described.

Fig. 111.



This disadvantage led to the suggestion, two or three years ago, by Mr. Wenham, of a method of dividing the pencil by the interposition of a transparent plane reflector, which, by being adjusted to a proper inclination, might reflect one half the light of each pencil, and allow the other half to pass through. This plan involves necessarily the sacrifice of stereoscopic effect, but it secures to the observer the great comfort and benefit which results from the equal use of the two eyes. It has proved practically somewhat difficult to carry out satisfactorily this idea of Mr. Wenham. His own first form of the instrument did not satisfy himself. More recently, Messrs. Powell and Lealand, of London, have patented a combination of prisms, which is believed by them to accomplish the object aimed at as well as could be reasonably demanded. This is represented in the figure annexed. The compound pencil from the objective, indicated by the line *op*, is partially transmitted through the quadrangular prism A, and partially reflected to the triangular prism B, by which it is again reflected to the eye. The two halves of the original pencil cross at *s*, for the purpose of preventing pseudoscopic effects; but this is unnecessary, since to the ordinary observer

there is no perception of relief, either true or false, produced by the combination. The disadvantage of this system is a great inequality of light in the two fields; the image formed by reflection being much inferior to the other in brightness. There is also a considerable loss of light by reflection at the second surface of the rectangular prism. Notwithstanding these disadvantages, this binocular is a valuable contribution to the resources of microscopists, many of whom profess to experience from the inequality of illumination no serious inconvenience.

As a convenient mode of distinguishing the two classes of binocular microscopes from each other, this which has last been described may be called the *catadioptric* instrument, implying that the division of the pencil is made by reflection; and the former the *stereotomic*, which expresses a division geometrically or mechanically made by cutting through the solid represented by the bundle of rays.

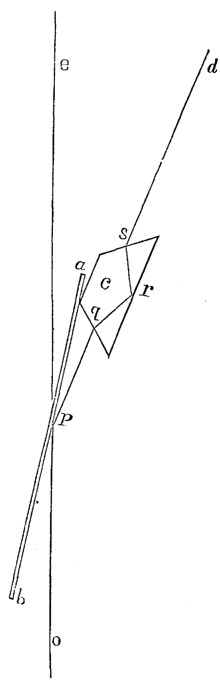
Mr. R. B. Tolles has constructed an instrument on the stereotomic principle, designed to remedy the difficulty above pointed out as attending the original binoculars; while at the same time it secures the incidental advantage of permitting any ordinary single-tubed microscope to be used as a binocular. This is a double eye-piece provided with a system of prisms in all respects like those of Mr. Nachet's earliest form of binocular microscope, but designed to divide the compound pencil of light at a distance from the objective about equal to that of the ordinary eye-pieces. From what has been said above as to the necessity, in order to secure equality, of making the division where the axes of the pencils cross, it is obvious that the method of Mr. Tolles is only available on condition that the axes be made to cross a second time; that is, that the erecting form of eye-piece be employed. An eye-piece of this description produces, first, an inverted image of the object, and secondly, a direct image, which is the image seen. Between these two images the pencils cross, and the point of crossing is the proper place for the dividing prism of the binocular eye-piece. Since the image observed has the same position as the object itself, it would seem at first thought that the division of the compound pencil ought to be made in the manner employed by Dr. Riddell, by means of rectangular prisms; but such a construction, paradoxical as the statement may seem, leads to pseudoscopic effects. The equilateral prisms of Nachet are used by Mr. Tolles, and each half of the divided compound pencil is sent to the opposite eye. The necessity for this mode of distribution will be recognized if we disregard the real object and the objective, and consider the first image to be itself the object under observation. The conditions are then the same as present themselves in Nachet's original binocular. In that case, if the eye could be put in place of the dividing prism and the objective taken out of the way, the real object would appear in its natural position. But the objective inverts the object, so that when the image is duplicated by means of the dividing prism, the halves must cross in order that each may reach the eye to which it belongs. In the binocular eye-piece under

consideration, the eye placed at the point occupied by the dividing prism would see the inverted image as if it were a real object; and as this image is again inverted afterwards, the same necessity exists as before for crossing the halves of the divided compound pencil.

As the point of second crossing of the simple pencils is invariable in position, this eye-piece works with objectives of all powers and with perfect equality of illumination in both fields. It is liable to the objection of a loss of light by the multiplication of surfaces of transmission; but this is not greater than attends the catadioptric binoculars thus far invented. Moreover, Mr. Tolles has pointed out the possibility of reducing the number of surfaces so that it shall not exceed the number necessary in an ordinary binocular, by giving a spherical curvature to the surfaces of transmission of the prisms employed, and thus combining a lens, or two lenses, and a prism in one solid; but it is believed that he has not as yet illustrated this possibility by a practical example.

A new form of catadioptric binocular has been proposed by Professor H. L. Smith, and described by him in the American Journal of Science for January, 1868, which much more equally divides the compound pencil than the combination of Messrs. Powell and Lealand described above, and on this account is more satisfactory to those observers who find inconvenience from the unequal illumination spoken of as occurring in that. The diagram here presented shows the essential parts of Professor Smith's device. A thin transparent plane reflector is shown at *ab*. A ray of light proceeding from the object encounters this reflector at the point *p*, and is in part transmitted without change of direction in *pe*, and in part reflected, encountering the truncated rectangular prism *c*, in which it undergoes a second reflection to correct the reversal produced by the first, and emerges in the direction *d*. The inequality of illumination mentioned as occurring in the binocular of Powell and Lealand is a consequence of a too small angle of incidence upon the first reflecting surface. In Professor Smith's instrument, the inclination of the mirror to the incident ray is such as to produce a sensible equality between the intensities of the reflected and transmitted light. An inclination of the plane of the mirror 80° to the axis of the telescope has been adopted by Professor Smith, and is found to answer the purpose. It was the original design of the inventor to make the reflector so far wedge-shaped as to throw the reflection from the second surface out of the field, but actual experiment showed that a very slight inclination of the two surfaces to each other was sufficient to make the two images coalesce, at least for a determinate position of the eye-piece, which is

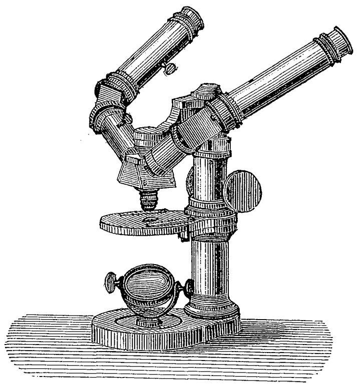
Fig. 112.



easily found by trial. The only instruments as yet made on this plan have been constructed by Professor Smith with his own hands. The writer, by actual experiment, has found the performance to be in a high degree satisfactory.

Mr. Nachet exhibited in the Exposition a binocular dissecting microscope of a neat and compact form; and another still simpler was exhibited by Mr. J. Beck.

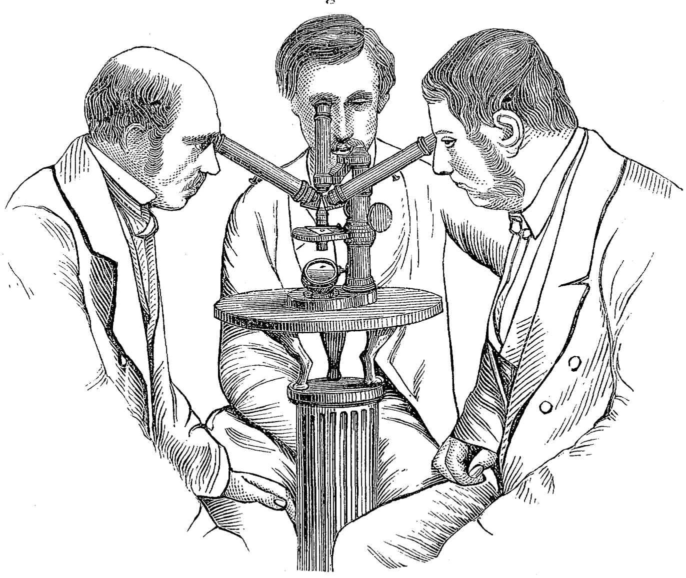
Fig. 113.



Double Microscope.

The division for purposes of binocular vision of the compound pencil of light proceeding from the objective, suggests naturally the adaptation of the instrument to the use of two observers simultaneously. A double microscope constructed on this principle by Mr. Nachet is represented in the accompanying figure. It is obvious that, after the division of the beam, it is only a matter of mechanical detail to give to the parts any direction which may be found most convenient. For purposes of demonstration, or in the prosecution of concerted observation, simultaneous observation of the same object is not only convenient, but is also greatly economical of time. Moreover, when the objects observed are moving, it is next to impossible for two observers successively to identify the same aspects. These considerations give great

Fig. 114.



Nachet's Triple Microscope.

practical value to the double microscope when used for purposes of instruction; and to those who observe merely for the satisfaction of curi-

osity they add very much to the interest of the observation, and the attending gratification. These remarks are still more applicable to the triple and quadruple forms of the instrument constructed by the same ingenious maker. The triple microscope of Mr. Nachet, as exhibited in the Exposition, is represented in Fig. 114. The beam of light from the objective is here divided into three equal parts by a combination of prisms of suitable form, each portion being reflected into a separate tube. As the eyes of different observers require different adjustments, each one of these tubes has a sliding tube within it, by means of which a large movement may be given to the eye-piece, permitting it to be adjusted separately to the point of most distinct vision; while a preliminary general adjustment for the whole may be obtained by means of a rack and pinion which varies the distance of the objective from the object.

By reference to the figure given further back, of the more recent form of binocular introduced by Mr. Nachet, it will be observed that a slight modification of the second reflecting prism would suffice to convert that binocular into a double microscope for two observers. Or, in fact, since in this case the second tube may be definitely fixed in its inclination to the first, a single prism of four or five sides might be substituted for the two of the binocular, with the advantage of diminishing the loss of light by the suppression of two of the surfaces of transmission. By this means any ordinary microscope may be converted, temporarily or permanently, into a microscope for two observers, at a comparatively trifling expense. This form of double microscope, as constructed by Mr. Nachet, performs very satisfactorily.

In conclusion, it may be observed of the microscopes and microscopic apparatus exhibited at the Exposition, that the advantage in regard to display was altogether on the part of the British exhibitors, while the superiority in respect to performance must be ascribed to the immersion lenses of the French. The microscope stands of the continental makers are much less elaborate than those of the English, or those preferred by our own observers. The American objectives of Messrs. Wales and Tolles were presented under some disadvantage, since they were unaccompanied with stands, but their merit was recognized by the jury and they were very honorably distinguished in the awards.

The neglect of the American exhibitors to send out stands was the more to be regretted, inasmuch as the stands made by some of them are admirable in design, convenient in use, and superior in workmanship. Nothing could be more elegant or tasteful than the first class stands constructed by Zentmayer, of Philadelphia. Mr. Tolles has also produced very fine stands. A masterpiece of this kind, constructed by him from designs furnished by the present reporter, possesses some important and peculiar advantages. The movable stage is provided with two tables, one facing, as usual, upward, and the other facing downward, which are firmly connected together, and have a common move-

ment, controlled on both sides by milled heads in both co-ordinate directions. When the object is used on the inferior stage, it is secured by spring clips, easily managed. In this case the central part of the superior table, which is removable, is taken away, and the objective descends through the opening. Any degree of obliquity of illumination, extending even to ninety degrees, can by this arrangement be brought to bear upon the object—an advantage which is secured by no other form of stand. The stage of this instrument is also capable of revolution on the optical centre throughout the whole circle. The same thing is true of the latest improved stands constructed by Messrs. Powell and Lealand; but in these there is the disadvantage that, in certain azimuths, the double milled heads controlling the movements are inaccessible, and the movement of the stage is possible in only one of the co-ordinate directions; while in the stage by Mr. Tolles, above spoken of, when one pair of milled heads is out of reach the other pair is always available. This instrument is also distinguished by numerous minor peculiarities, which greatly facilitate observation and promote convenience of management.

VI.—ELECTRICITY.

Instruments intended for the illustration of electrical phenomena, or designed as aids to experimental research in electrical science, arrange themselves naturally under the two heads electrostatics and electrodynamics. In considering the electrical apparatus exhibited in the Exposition, this distinction will be observed.

STATIC ELECTRICITY.

The forms of electrostatical apparatus which have in late years excited the highest interest, have been those in which advantage is taken of a disturbed state of electrical equilibrium produced by induction, to accomplish the direct transformation of mechanical force into electricity. Of the several machines operated upon this principle which have obtained a certain favor, that which is most widely known, at least in this country, is the one which is named from its inventor the Holtz electrical machine. Next to this, the most remarkable are the machines of Töpler, of Russia, and of Bertsch, of Paris. All of these illustrate the direct transformation of mechanical force into electricity; and all of them, as it respects construction, are essentially transformations into a new shape of the simple, and as commonly constructed quite inefficient, apparatus, called the electrophorus.

The idea of accumulating electricity by multiplying the effects of induction is not entirely new. Several forms of the condenser have been constructed expressly to apply it. Thus, the three-plate condenser of Peclet is designed to afford the means of obtaining electricity of high tension; though the quantity accumulated by it is after all very trivial, while the process of accumulation is both slow and troublesome. In

1848, Svanberg described to the British Association for the Advancement of Science an arrangement superior to Peclet's for accomplishing the same object; but this, too, was an apparatus too difficult successfully to manipulate, and too slow in producing results, to be of any practical use. Yet Svanberg's apparatus, properly managed, was capable of producing sparks from a single cell of Daniell's battery.

In 1862, Mr. C. M. Varley, of London, electrician to the Atlantic Telegraph Company, exhibited at the international industrial exposition an instrument by means of which feeble electrical tensions could be multiplied several thousand fold; and this without any of the troublesome operations by hand which made the methods of Peclet and Svanberg tedious and uncertain. A simple rotation was substituted in place of a complicated series of transfers, and mechanical contacts took the place of contacts with the finger. Mr. Varley's machine was therefore perfectly uniform in the results which it produced; the total effect being proportional to the number of rotations given to it, and being capable of calculation in advance. In exhibiting the performance of his instrument to the jury, Mr. Varley furnished a practical proof of this uniformity of action by first multiplying the tension of the positive pole of a Daniell's cell by a definite number of rotations, and measuring the intensity of the accumulated charge by means of a portable Thompson's electrometer; and afterwards reversing the direction of rotation and turning twice as many times in the opposite direction, and measuring in the same manner the final resultant, which was negative and which proved to be of an intensity almost exactly equal to the first. Sparks were produced by this machine from a single Daniell's cell without difficulty, and Mr. Varley stated that he had obtained a multiplication amounting to fifteen thousand times the tension of the original source. As this machine was the first in which the accumulation of electricity by influence, in a continuous manner, in considerable quantities, and of a high degree of tension, was practically proved to be possible, it is but justice to the inventor, although his machine has not come into general use, that, in a matter of so much scientific interest, he should receive the credit due to an undoubted priority.

Before proceeding to speak of the machines of more recent inventors, it will not be out of place to present a brief description of the earlier form of static induction apparatus contrived by Mr. Varley. The following account of this apparatus is transcribed from the reports of the jury on the Exposition of 1862.

VARLEY'S STATIC INDUCTION APPARATUS.

"The instrument might be called a multiplying inductor. It consists of an axis on which parallel rows of insulated brass vanes or arms are fixed; the description will be simplified by considering one row of vanes only, A, B, C, D, &c. The axis may be turned by hand, and at two points of the revolution diametrically opposite to each other the vanes

enter two rows of hollow insulated coverings or shells of brass, a, a_1, a_2, a_3, &c., and b, b_1, b_2, b_3, &c. These shells conceal the vanes entirely on three sides, and are connected one with another as follows: a unconnected, a_1 a_2 joined together, a_3 a_4 joined together, a_5 a_6 joined together, &c. In the opposite row b b_1 are joined, b_2 b_3 joined, b_4 b_5 joined, &c.; a is opposite b, a_1 opposite b_1, &c. Thus the two rows may be said to be arranged in alternate insulated couples.

"The charge to be multiplied is communicated to a, and we will first suppose this charge to consist of a certain definite quantity, retained without loss by means of perfect insulation. The axis is next turned round by hand; when the vane A is inside a, an earth connection is made at the inner end of the vane A, where it is not covered by the shell. If the charge on a be positive, a negative charge of corresponding magnitude will be induced on A. The charge so induced may approach more or less nearly, according to the proportions of the instrument, to equality with the charge on a; it will always be somewhat less, but can easily be made in practice to differ very little from the original charge. When the axis is turned round still further, the earth connection is broken, and the negative charge remains insulated on the vane A. As the axis continues to revolve, the vane A is brought inside the shell b, and is then put in connection with the shell b b_1 by a suitable contact. The negative charge on A will then almost entirely distribute itself over the outer surface of the double shell b b^1. As the axis is turned round and round, the same series of contacts will be repeated; successive charges on a will be induced by a, and communicated to the double shell b b_1, on the surface of which these charges will gradually accumulate, tending towards a limit which is only not infinite, (leaving insulation out of consideration,) because when the vane is inside b b_1, and its contact there made, its whole metal is not surrounded by a closed metal forming part of b. The effect will, however, practically be limited rather by imperfect insulation than by the want of continuity in the surrounding surface of b b_1. But while negative electricity is thus accumulating on b b_1, the second vane, B, has been continually passing through the shell b_1. At the moment when fully covered by this shell, an earth contact has been made with this vane as already described by vane A. B has, therefore, been receiving continually greater charges of positive electricity, each very nearly equal to the quantity of negative electricity at that time on b b_1, and these in their turn it has communicated to the shells a_1 a_2. The vane C receives continually increasing negative charges from a_1 a_2, which it communicates to b_3 b_4, and thus the multiplication proceeds through any required number of vanes and shells, by the simple process of turning the axis.

"If all the vanes and shells be alike, and if one vane with its pair of shells can, at most, produce a charge in the second shell only ten times greater than that in the first, it is clear that ten vanes and their shells would produce a maximum charge in the final shell 10^{10}, or 10,000,000,000

tion which it has just completed. In the mean time Q has received and times greater than that on the first shell. The tension of this final shell, if all disturbing causes be removed, would likewise be 10,000,000,000 times greater than that of the first shell under similar circumstances. Metallic screens in connection with the earth are used between each pair of coupled shells to prevent their action one on the other, and also surrounding the whole apparatus to screen it from irregular electric induction. If, instead of giving the first shell *a* a certain definite quantity of electricity, it were maintained at a certain constant by contact with a source of electricity, (for instance connected with one plate of a battery, while the other is in connection with the earth,) the result would be exactly similar to that which would be obtained if a definite quantity, equal to that contained in the shell *a* when the vane A is inside it and the earth contact made, has been communicated to the shell *a* in the first instance. The actual multiplication for each number of turns would, when the insulation is good, be perfectly definite; but could in this arrangement be practically determined by experiment only. It was understood that Mr. Varley has, by slightly modifying the present arrangement, produced an instrument in which it is easy by calculation to determine the multiplication given by any fixed number of turns."

The electrical machines of Holtz and Töpler made their appearance almost simultaneously in 1866. The machine of Holtz is already quite extensively used in the United States as well as in Europe. It is constructed in an elegant form by Ritchie, of Boston, and also by the Messrs. Chester & Co., of New York. Töpler's is hardly known in our country at all. In both these machines a rotating disk is employed to carry electricity from a point where it is excited by influence to another point where it is accumulated. In Holtz's machine the carrier is a non-conductor, being the rotating disk itself, which is formed of glass. In Töpler's, in which a glass disk is also used, the use of the disk is to insulate a pair of conducting carriers; so that this machine has a pretty direct resemblance to that of Mr. Varley.

TÖPLER'S ELECTRO-STATIC INDUCTION MACHINE.

Töpler's machine will be first briefly described: In the annexed figure, on page 549, which represents only the essential parts of the instrument, without the sustaining frame, a circular plate of glass is shown, mounted on the axis RR′, to which is attached a crank. In point of fact, the velocity of rotation given to the disk, in practice, is greater than can be directly imparted by the hand; and the axis RR′ is turned by a pulley driven by a larger wheel, to which the power is immediately applied by means of a band. The disk is coated, over a pretty large extent of the surface of each semi-circle, by tinfoil sheets, P and Q. These sheets are applied on the side of the disk toward the fixed plate P′, and are made large enough to fold over the circular edge and admit of being pasted down, so as to form on the crank side of the disk the annular coatings *p q*. These sheets and annular bands are separated from each

other by an intervening space of uncoated glass. The fixed plate P′ was originally constructed by the inventor, of metal, insulated by the three supports $s\ s'\ s''$, and placed at a distance of not more than five milli-

Fig. 115.

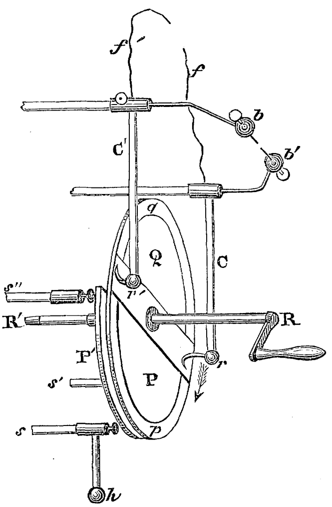
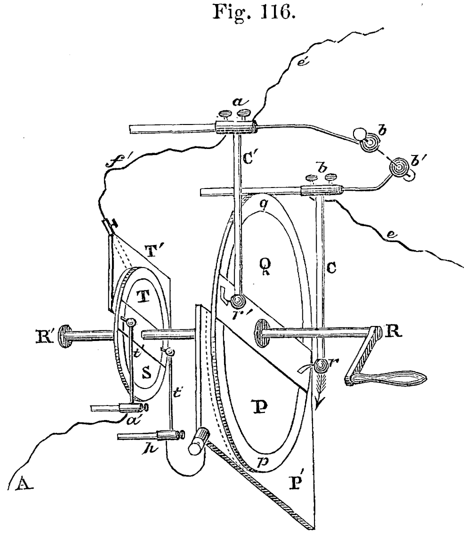


Fig. 116.



Construction of Töpler's Machine.

meters from the disk; but he has since, for a reason which will presently appear, made it of thin glass, coated, on the side most distant from the disk, with a sheet of tinfoil equal in size to P or Q. Two vertical conductors, C and C′, are attached to the horizontal insulating supports shown in the figure; and are put into communication with each other or with the ground, at pleasure, by means of the wires f and f'. To the conductors C and C′, are added the rods and knobs b and b', which last are furnished with points directed toward each other and adjustable at different distances. The conductors are also put into communication by contact with the bands p and q, by means of light metallic springs r and r'.

Such being the construction of the machine, its operation is as follows: P′ is put into conducting communication with some feeble but constant source of negative electricity, as, for instance, the negative pole of a dry-pile. The conductor C is made to communicate with the ground by means of the wire f; and C′ is insulated. The negative electricity of P′ induces a positive charge in P, which, in the course of the rotation, is in conducting communication with C, and therefore with the ground, until the moment before it reaches the position represented. Its own negative electricity, therefore, escapes by that channel. In the position which, in the order of rotation, immediately succeeds that represented, P will be in communication with C′ by means of the spring r'; and the positive electricity with which it is charged will pass off principally upon that. It will directly after come into communication with C, and so will be restored to its natural state, and prepared to repeat the opera-

carried a similar charge to C′, in like manner. There is a limit to the extent beyond which the accumulation produced by this succession of transfers cannot be carried. When the intensity exceeds a certain moderate amount, sparks begin to pass between P and P′. It was with the view to diminish this liability to a discharge, which neutralizes the power of the machine, that Mr. Töpler substituted for the metal plate P′, a thin glass plate coated on the side most remote from P. He also thoroughly varnished the metallic coating P itself. These changes have been attended with improvement; but they have not removed the difficulty. It is only possible to prevent a shower of sparks between P and P′, by substituting a discharge between C and C′, through the points *b* and *b*′. A distance may be found by trial, at which if these points are fixed, the machine will work without a backward discharge upon the exciter P′. But this limits its power of accumulating electricity upon a given conductor. Owing to the tendency by backward discharge to the neutralization of the excited condition of P′, it is necessary to maintain permanently the communication between this surface and the original and constant source of negative electricity. But Mr. Töpler, by an ingenious expedient, has contrived to evade this necessity, by making the machine itself contribute the supply of electricity essential to the maintenance of the excited state of P′. This consists in establishing upon the same axis RR a second disk and accompanying apparatus, forming a miniature copy of the first, as shown in Fig. 116. The only difference is that the exciting plate of the small apparatus, marked in the figure T′, is reversed in position from that of the large apparatus, which is P′. This second exciting plate communicates through the wire *f*′ with C′; which last is charged, as we have seen, positively. T′ is therefore positive, and T is accordingly negative, producing an accumulation of negative electricity in the conductor *t*; which again imparts to P′ through the wire connection represented, the constant supply of negative electricity necessary to maintain the activity of the large machine. The conductor *t*′ of the small apparatus communicates with the ground by the wire A.

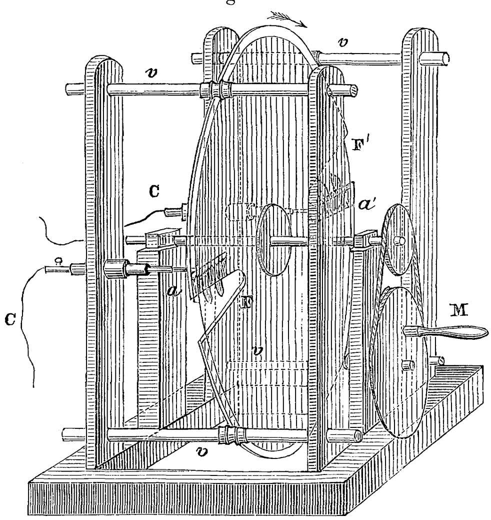
A curious fact manifests itself in the operation of the machine with these arrangements. In its original form, no electrical action would take place unless P′ were first electrically excited by communication with some source of electricity exterior to the machine. In the modified form it excites itself. It is only necessary to turn it a few minutes in order to bring it into a condition of as high activity as can be desired. This effect is consequent upon the power of the machine to increase by accumulation the smallest original charge, even though it should be so small as to be quite insensible; or to add to a minute disturbance of equilibrium until it becomes a large one. If there is any unequal distribution of electricity in the machine, therefore, at the moment when it is set in motion, it will immediately charge itself. If there is no such inequality, it is not at first obvious how the initial disturbance of equilibrium is produced. Töpler ascribes it to the friction of the air, or of the

springs. The latter hypothesis is the most plausible, inasmuch as these springs run at intervals upon glass, and one of them is always insulated. Suppose, for instance, that by the friction of r' on the glass, this spring, with its connected conductor C′, becomes positively electrified, however slightly, T′ will become positive, and T t and P′ negative. The conditions are now such as to induce the regular series of reactions which we have described, and to bring the machine speedily into a high state of activity.

In the Russian section, a Töpler machine was exhibited by Mr. Wesselhoft, of Riga, embracing a combination of ten or twelve plates. This was inclosed in a glass case, and designed to be permanently so. At one extremity of the box an aperture in the glass allowed the axis to pass through in order that the power might be applied externally. The machine, which was unfavorably situated for close examination, being hemmed in by other objects on exhibition, presented too great a complication of parts to be easily made out in its details; and it was neither exhibited in operation nor accompanied by any explanation. Of its powers of performance, therefore, nothing could be ascertained, although inquiry was made of gentlemen connected with the Russian commission. Töpler's machine requires to be driven at the rate of fifteen to eighteen turns in a second. For reasons which will be apparent from the foregoing description, it does not furnish high intensity or produce long sparks; but the quantity it will generate in a given time is quite remarkable. With two disks mounted as above described, and of the diameters of ten and fifteen inches respectively, a Leyden jar exposing one hundred and sixty square inches of coated surface is charged in less than half a second.

HOLTZ'S ELECTROSTATIC INDUCTION MACHINE.

Fig. 117.



Holtz's Electrostatic Induction Machine.

The machine of Holtz in its original form is shown in the accompanying figure. Its principal parts are, first, a thick circular plate of glass, secured by four horizontal supports v v v v, forming part of a frame; second, a very thin and rotating disk of glass, fixed to an axis, which passes through the thick plate by an aperture sufficiently large, and is driven by a pulley and multiplying-wheel operated by the handle M; the thin disk is on the side of the thick plate most distant from the handle, and from the ob-

server in this perspective view, but is very near it; third, two sets of points, or electrical combs, in insulating supports, and with binding screws for the attachment of conducting wires C and C′; fourth, two openings or sectoral cuts, in the circumference of the fixed plate at F and F′, of each of which one of the straight sides in the radial direction is armed with a coating of paper furnished with points also of paper or card-board, placed parallel to the rotating disk, but having a direction opposite to that of the rotation.

In order to bring on electrical action by means of this machine, one of the paper armatures is charged with electricity by exciting a plate of glass, a stick of sealing wax, or a piece of ebonite, by friction, and bringing the excited body into contact with the armature. On turning the machine, electricity accumulates in the insulated conductors connected with the combs, and the second armature acquires an electricity opposite to that which was given to the first. The electricities of the two conductors are of the same name with those of their adjacent armatures. In order to bring on the action of the machine expeditiously, it is advisable to put C, for a moment after exciting the armature, into communication with C′. This precaution is, in fact, nearly indispensable.

In order to understand this action, let us suppose, at first, that the armature *a* is charged positively, and the armature *a′* negatively; and, for the sake of simplifying the matter as far as possible, let us consider what ought to be the effect, supposing that there is no rotation of the intervening disk. The inductive influence of *a* on the conductor connected with the adjacent comb will draw out of that conductor its negative electricity, which will be intercepted by the glass and held there, while the positive electricity of the same conductor will be set free and driven *from* the disk. The armature *a′* will produce a corresponding but reverse effect on the conductor C′; so that this conductor will be charged negatively, and C positively. If, then, these conductors be brought near each other, a spark will pass between them. But if, without discharging them in this manner, we suddenly reverse the position of the glass disk intervening between the combs and the armatures, the negative accumulated electricity which was drawn out of C by *a* will be brought opposite to *a′* by which it will be repelled from the plate and driven to join the negative charge already accumulated in C′. And simultaneously, the positive electricity which *a′* had drawn from C′ upon the disk, will be brought into a position in front of *a*, by which it will be driven into the conductor C.

It is further to be considered that the effect of the original charge in drawing negative electricity out of C can only be proportioned to the strength of the charge. When, therefore, by rotation, the disk has rid itself of these first charges drawn to it by the inductive influence of the armatures upon the conductors, the same influence suffices to draw fresh charges of the same kind as the first from the same conductors; and thus, the rotation continuing, the accumulation goes on.

It remains to be considered how the second armature becomes negatively charged, when only a positive charge is communicated to the first. There is no difficulty in understanding this, if we suppose the conductors C and C′ to be in communication in the first instant. The armature *a*, charged positively, not only draws the negative electricity of C through the comb-points down to the plate, but it drives the positive electricity of C and of the plate also to the opposite extremity of that conductor. This opposite end, when C and C′ communicate, is virtually the comb opposite *a′*. The positive electricity of C and C′ therefore tends to flow out of the comb-teeth to the plate, and this electricity, accumulating there, induces a negative condition of the armature *a′*. The paper points attached to the armature facilitate the assuming of this electrical state, and discharge some positive electricity which the presence of the similar electricity upon the disk causes to diffuse itself in the air.

If there is no preliminary contact of C and C′, more time will be consumed in bringing the machine to activity. In this case the negative electricity drawn out of C by *a* comes, as it approaches *a′*, under the influence of the paper points connected with the armature. The repulsive force which it exerts on the negative electricity of the opposite side of the disk, and its attraction for the positive electricity in *a′*, cause an exchange through the paper points between the armature and the plate, before the comb opposite *a′* can act. Thus there will begin to accumulate upon *a′* a negative charge, which will slowly increase.

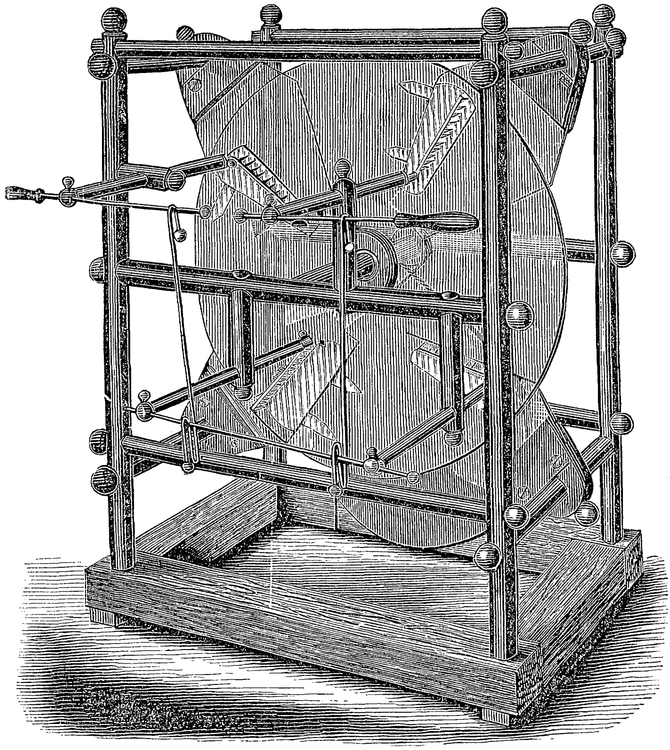
Mr. Holtz thought it necessary to shield the rotating disk by the fixed disk, all over its surface, except where the armatures are placed. His impression was that the charges carried by the revolving disk are disguised by the influence of the fixed disk, and set free only when they come opposite to the openings, or *windows;* and it was his opinion that this construction is necessary to secure transportation without loss. Our American constructors, however, do not employ a fixed disk, but substitute instead of it as many wedge-shaped or sectoral plates of glass as there are armatures to sustain, and give to these only breadth enough to afford the necessary strength. In this construction the transported charges on the disk are left without any such supposed protection for the greater part of the course. The modification here described does not seem to be attended with any sensible disadvantage. It is represented in the accompanying figure (Fig. 118) taken from a machine constructed by the Messrs. Chester of New York.

CHESTER'S HOLTZ MACHINE.

The distance at which the revolving disk is placed from the fixed plate is as small as it can be conveniently made, say one-tenth of an inch. The paper armatures cover the whole edge of the "window," and extend a little on the inner side; but their greatest breadth is on the outside. The number of turns given to the disk per second is about the same as

stated above in speaking of Töpler's machine; that is to say, fifteen or twenty to the second. In the machine as represented in Fig. 117 there are but two "windows" and two sets of combs. Four windows and four

Fig. 118.



Chester's Holtz Machine.

combs are employed, with an increase of the quantity generated, but with a diminution, diameters of plates being equal, of striking distance. A twenty-inch plate with four sets of combs will charge a Leyden jar of one hundred and sixty square inches in less than a second.

A curious modification of the Holtz machine, devised by the inventor himself, and constructed by Mr. Rohrbeck, of Berlin, by whom it was exhibited in the Exposition, consists of a pair of rotating disks of glass, turning with great velocity in opposite directions, and without any "windows." At the extremities of two diameters, at right angles to each other, are placed four combs, opposed to the surfaces of the revolving plates, and united by pairs to form two poles. This contrivance was not seen in operation, and nothing is known of its efficiency.

BERTSCH'S ELECTROSTATIC INDUCTION MACHINE.

The machine of Mr. Bertsch, which is the latest of these induction machines, is also the simplest. It consists of, first, a thin disk of glass to be rapidly rotated, as in the case of the Holtz machine; second, a plate

of ebonite, to serve as the exciter of electricity by induction; third, two sets of combs with their associated conductors. The ebonite plate is excited by friction with fur or silk, and then put in place opposite the lower limb of the plate, and as near to it as it can be placed conveniently. One of the combs is immediately opposite to this plate; the other, 180° from this. The excited plate, excited, we will suppose, negatively, draws the positive electricity of the lower conductor to the disk through the comb-teeth, and this electricity, in the rotation of the disk, is discharged through the opposite set of comb-teeth upon the upper conductor. Thus the theory of this machine is simply that of a continuous electrophorus. In its construction it is much simpler and less liable to derangement than those of either Holtz or Töpler: it is little inferior to them in its effects in any respect, and for some uses it is superior.

The effects of this machine are practically heightened by the introduction, into the construction of the conductors connected with the combs, of condensers, which, by suitable connection between the two, make of these conductors a sort of masked Leyden jar. The intensity of the discharges, as well as the quantity retained in the conductors, is thus much increased.

A Bertsch machine of twenty inches diameter, two exciting plates and four combs, will furnish sparks four to eight inches long, and eight or ten in number per second. It will charge a battery of twenty square feet of surface in from one-half to three-quarters of a minute.

DYNAMIC ELECTRICITY.

Dynamic electricity is now applied to so large a variety of purposes, that every improvement in batteries, whether as it respects their power, or permanence, or economy, is a matter of great interest. The batteries of Grove and Bunsen have not been surpassed in energy, and probably will not be; but they evolve fumes which render their presence offensive, a disadvantage which necessitates that they should be shut up in closed chambers with special arrangements for ventilation. Moreover, though they are sensibly constant in action while the acids are fresh, the action must fall off as these liquids are exhausted, and they require to be charged anew sufficiently often to make their maintenance troublesome.

For very many purposes, a current of low intensity steadily sustained is of much greater importance than a more powerful one of less duration. This is true in all the operations of galvanoplasty and in the apparatus of electric horology; and it has even been found to be true of the Atlantic telegraph. The attention of electricians has therefore been specially turned, in recent years, to the construction of batteries capable of long-continued action, and which can be left to themselves without apprehension of their failure for periods of many months.

HYDRO-ELECTRIC BATTERIES.

The sustaining battery of Daniell, invented in 1836, was the first which possessed to any degree the character of permanence. In its

original form it presented some practical inconveniences which do not exist in the modifications which it has since undergone. But even in its original and comparatively imperfect shape, it was a gift of inappreciable value to electrical science and to all its applications; and it first made practially feasible the project, which was before but a tantalizing and doubtful possibility, the electric telegraph.

Daniell's battery consisted of a zinc and a copper element, each immersed in a separate saline solution; the solutions being prevented from mingling by the interposition of a porous diaphragm. Leather or some kind of animal membrane was originally employed as the material of the diaphragm. These substances were subsequently replaced by porous earthenware. All forms of diaphragm are liable to some objections. If of membrane, they are not durable; if of pottery, they are fragile; and both kinds become sooner or later covered in parts with precipitated copper.

The unsatisfactory action and speedy loss of power of the battery which had been up to this time in use arose from the accumulation of hydrogen in minute bubbles upon the negative plate, obstructing free contact with the liquid, and to some extent polarizing the battery in the opposite direction. This evil was overcome at a later period by an ingenious expedient originated by Mr. Alfred Smee, of London, which consisted in replacing the copper element of the battery by a platinum plate coated with platinum electrically precipitated. The bubbles fail to adhere to the rough surface of the precipitated metal, and the obstruction above spoken of no longer occurs. Though Mr. Smee employed plates of platinum in his original arrangements, less costly metals serve equally well, when platinized on their surfaces. Silver has been generally substituted for the platinum of the plates; and as the thickness may be very small, the expense is not considerable. More recently, iron has been also used for the same purpose, with satisfactory results.

In the Austrian section of the Exposition there was exhibited a Smee battery, by Colonel Ebner, of the imperial engineers, in which platinized lead had been employed as the negative element. The cups of this battery are large, measuring about twenty inches high by five inches in diameter. The lead is in the form of a hollow cylinder smaller in diameter than the cup, and supported by a flange which rests on the top. It is immersed to the depth of only six or seven inches, the design of the great capacity of the cup being to protract the action of the battery, by allowing a large quantity of the exciting liquid to be introduced. The top of the cup is covered by a disk of porcelain, with perforations to allow the electrodes to pass through, and to permit the introduction of the liquid after the apparatus has been arranged. A stopper is adapted to the orifice intended for this latter purpose, to prevent as far as possible evaporation. The positive element, which is formed of zinc, is not moulded into any particular shape, but is introduced in fragments into a small bucket of porcelain with large openings in its sides for the free

admission of the liquid. The zinc is amalgamated, and the bottom of the bucket contains an excess of mercury by which the amalgamation is maintained. This bucket is suspended in the middle of the hollow cylinder of platinized lead, by means of a hollow stem which extends to the bottom of the bucket, and rising through the porcelain cover is sustained by a flange. This hollow stem gives passage to the electrode on the side of the zinc. The exciting liquid is weak sulphuric acid. Apart from the peculiarities of arrangement, and the large relative size of the cups, there is nothing novel in this battery except the platinized lead. It is said to be in use in Austrian telegraph offices.

The evil above spoken of which Mr. Smee's contrivance was designed to obviate, *i. e.*, the accumulation of hydrogen upon the negative metal, was overcome in the battery of Daniell by the decomposition of the salt in contact with that element and the union of the oxygen of its base with this hydrogen to form water. The salt on the positive side is not necessary to the action of the battery, but promotes its activity, by increasing the conducting power of the liquid. In the nitric acid batteries of Grove and Bunsen, the hydrogen is suppressed by oxidation in a manner analogous to that above described. Daniell's battery is simplified by employing but a single saline solution, this being kept constantly saturated on the side of the negative element, while on the positive side the liquid is nearly pure water.

A simple but very permanent battery of low intensity constructed on this principle was introduced some years since by Mr. M. G. Farmer, of Boston, and was employed, as it probably still is, in connection with the system of electric fire-alarms in that city. This battery consists, first, of an oval-shaped copper vessel, which constitutes the negative element and which is nearly filled with a saturated solution of sulphate of copper. Within this, at one end of the oval, is placed a porous cup, and within this a smaller porous cup designed to receive a cylinder of amalgamated zinc, which forms the positive element. The zinc being in place, pure water is poured into the smaller porous cup and a weak solution of sulphate of copper into the larger. The saturation of the liquid in the outer or copper vessel is maintained by placing a third porous cup in the opposite end of the oval, filled with crystals of sulphate of copper. As these crystals are gradually dissolved, the supply in the cup is from time to time replenished. No other attention is necessary except to see that the water does not fall too low. These matters being properly provided for, the battery will continue to act without sensible variation of energy for many months. Three cells of this battery, employed by the writer to drive an electric clock, performed satisfactorily for six months or upwards without change. The power was a good deal in excess of the necessity of the case. A single cell sufficed to drive the clock. The others were added for security.

Quite analogous to this, but essentially different in arrangement, is the battery devised by the Rev. Father Secchi, of Rome, and exhibited in

the Exposition in connection with his interesting *météorographe* elsewhere described. In this battery, a hollow cylinder of copper, notched at the bottom to permit a free communication between the liquid within and without, is placed upright in the middle of a deep cup of glass or earthenware, and the bottom of the cup is covered with crystals of sulphate of copper. On the top of the salt is formed a stratum of bibulous paper outside of the copper, the paper being cut into rings having dimensions corresponding to the section of the annular space. Then follows a stratum of sand, on which rests a hollow cylinder of zinc surrounding the copper. The interior of the copper cylinder is filled with powdered sulphate, and the filling of the remaining space on both sides of the zinc is completed with sand. The whole is then moistened with water. This battery is very constant. According to the statements of Father Secchi, it acts for an entire year, requiring no other attention than the occasional addition of water and a small quantity of sulphate of copper.

The batteries of Mr. Callaud, of Nantes, and of Mr. Minotto, of Turin, are very similar to that of Father Secchi. In the first, a plate of copper in a horizontal position is imbedded in a stratum of crystallized sulphate of copper at the bottom of the cup. To this is soldered a conducting wire protected by a coating of gutta-percha. A saturated solution of sulphate of copper is poured into the cup until the stratum of salt is covered, and the remainder of the cup is filled with pure water. In the upper portion of the cup is suspended a hollow cylinder of zinc, which rests upon the top by a flange. The second differs from this in having a stratum of sand over the bed of salt at the bottom of the cup, and using the sulphate not in crystals but in powder. These batteries require to be charged anew as soon as the sulphate is exhausted, and in this respect are less favorable to long continued action than that of Father Secchi.

The sulphate of mercury battery of Professor Marie-Davy is a carbon battery, in which the bisulphate of mercury occupies the place of the nitric acid of the battery of Bunsen. This salt is nearly insoluble, and it is therefore reduced to powder and made into a paste by trituration in two or three times its volume of water, the excess of water being afterwards withdrawn. The electric action deoxidizes the mercury, which subsides to the bottom of the cup, while the sulphuric acid attacks the zinc and forms a sulphate.

Mr. Leclanché, of Paris, exhibited in the Exposition an ingenious form of battery, which, as stated by the Abbé Moigno in "*Les Mondes*," has been introduced into several telegraphic offices on the continent of Europe. This is also a carbon battery in which the peroxide of manganese takes the place of the nitric acid. In the earlier trials of this battery the manganese was introduced in fragments into the porous cup containing the carbon element. Mr. Leclanché has since found it better to grind it to powder and to employ a paste consisting of a mixture of this powder and carbon. The natural crystalline peroxide is the only

kind employed. The positive element is a stout rod of amalgamated zinc, and the exciting liquid is a concentrated solution of sal ammoniac.

In connection with these improved forms of the carbon battery may properly be mentioned the modification introduced a few years since by Professor Bunsen, consisting in the substitution for nitric acid, on the side of the negative element, of a solution of bichromate of potassa. On the zinc side the liquid is dilute sulphuric acid, as usual. This battery performs very well for a time; but, in consequence of the precipitation of the sesquioxide of chromium upon the zinc, it gradually loses power. Another modification consists in dispensing with the porous cup or diaphragm and using the two liquids in mixture. In this form the elements are combined by securing each plate of carbon between two plates of zinc, the whole being attached to a supporting disk of hard caoutchouc. The same difficulty occurs in this case as in the other; but it has been shown by Mr. Ruhmkorff that, if the carbons are four or five times as long as the zincs, the deposit of the oxide is very much retarded.

A remarkable battery, called by its inventor, Professor Jules Thomsen, of Copenhagen, a polarization battery, was exhibited in the Danish section. Fifty-two plates of platinum are immersed in dilute sulphuric acid, and these are successively brought into contact, by pairs, with the poles of a single cell of Daniell. In consequence of these contacts the plates become covered, by the decomposition of water, with oxygen on one side and hydrogen on the other. This polarization gives rise to a powerful current in the platinum combination; and this is maintained nearly constant when the contacts succeed each other rapidly and regularly. To secure this object, the electrodes of the exciting battery are kept in rotation by means of an electro-magnetic motor. Professor Thomsen states that the fifty cells which correspond to the fifty-two platinum plates produce a current equal in intensity to that of seventy-three elements of Daniell.

In an experiment made in the Exposition with this battery, by Mr. Sabine, of the British commission, with two Bunsen elements as the exciting battery, and thirty-eight rotations of the commutator per minute, producing nineteen hundred separate polarizing charges in the same time, the electro-motive force was equal to that of seventy Daniell's elements. This is considerably less than is claimed by Professor Thomsen; but it is possible that a greater or less velocity of rotation might have produced a better result.

THERMO-ELECTRIC BATTERIES.

Thermo-electric batteries were exhibited in the United States section by Farmer, in the Austrian by Marcus, and in the French by Ruhmkorff. The battery of Farmer consists of strips of copper and blocks of a kind of alloy of which the nature is not known, arranged alternately. The alloy is in wedge-shaped masses two inches in length and one in depth, with a breadth of half an inch at one end and one-quarter

at the other. This form was adopted to permit the convenient arrangement of the elements in a ring, the broad extremities being placed outermost. The strips of copper are introduced between these sectoral blocks and soldered to them by their opposite extremities alternately. Insulation between the metals is effected by the interposition of plates of mica. Heat is applied to the inner extremities, a circular gas burner being employed as the source. It is stated that thirty-six elements of this battery are equal to one of Grove's. The internal resistance is equivalent to that of sixty feet of copper wire No. 18. Some better arrangements appear to be necessary to maintain the depression of temperature in the outer extremities of the elements.

The battery of Professor S. Marcus, of Vienna, is composed of elements both of which are alloys. The positive element consists of ten parts by weight of copper, six of zinc, and six of nickel; the negative of twelve parts of antimony, five of zinc, and one of bismuth. These are connected in such a manner that the combination bears some resemblance to the roof of a house, the rafters, or separate elements, being soldered by their alternate extremities, and separated by a slight space with no intervening insulation. The system stands in the position of a roof, the lower edges which form the eaves being immersed in cold water. Heat is applied by means of a spirit lamp with a long wick extending beneath the roof from end to end of the system, and loss of heat by radiation is prevented by a screen or cover of earthenware, in the form of an inverted trough. One hundred and twenty-five pairs of this battery generate twenty-five cubic centimeters of mixed gases (nearly six and a half cubic inches) per minute. Sixty-five pairs are sufficient to develop a lifting force in an electro-magnet of twenty-five to fifty kilograms.

Becquerel's thermo-electric battery dates from 1865. It was discovered by this gentleman, in the course of his investigations, that artificial sulphuret of copper, when heated to two hundred or three hundred degrees centigrade, is strongly positive, and that a couple formed of this substance and metallic copper has nearly ten times the electromotive force of the ordinary copper and bismuth couple. This is remarkable, as the native sulphuret is strongly negative. The metal, however, employed in this battery along with the artificial sulphuret is not copper, but is an alloy of ninety parts of copper with ten of nickel, such as is commonly known by the name of German silver. The arrangement of the elements in the battery considerably resembles that of Marcus. Heat is applied by a gas burner, which, in the battery exhibited, consisted of a tube with perforations on its upper side extending along beneath the central line of junction of the elements. The outer extremities of the elements, as in the case of the battery previously described, are immersed in cold water. Eight or nine pairs of these elements are esteemed by Mr. Becquerel to be equal to one of Daniell's. With fifty couples an electro-magnet has been made to sustain a weight of one hundred kilograms. The intensity of the current is very great, and also the internal resistance.

ELECTRO-MAGNETS AND INDUCTION COILS.

An enormous electro-magnet, designed for investigations of diamagnetism, was exhibited by Mr. Ruhmkorff. The weight of the soft iron core of this magnet is no less than four hundred kilograms, (nearly nine hundred pounds,) and that of the enveloping wire is quite as great. Its lifting power is said to be fifteen thousand kilograms. The secondary spark produced in breaking the exciting current of this magnet is so powerful, that to the observer, the conductor itself seems to be bursting into flame. A rotation of the plane of polarization of a ray of light may be obtained in repeating with this magnet Faraday's celebrated experiment, amounting to no less than forty degrees.

A large electro-magnet which was exhibited by Professor Hamar, of Pesth, presents the peculiarity that the ordinary envelope of insulated wire is replaced by disks of copper. To what extent the power is increased or diminished by this construction, was not ascertained.

A very magnificent induction coil, the largest probably ever made, formed a part of Mr. Ruhmkorff's splendid exposition. Its height as it stands is seventy-five centimeters, or thirty inches. The length of the wire in the primary circuit is fifty meters; its diameter is two and three quarter millimeters, forming two layers upon the core. The wire of the secondary circuit is one hundred and fifty kilometers (ninety-three miles) long, and one-ninth of a millimeter in diameter. This wire is wound in disks—a mode of winding which, it is believed, originated with Mr. E. S. Ritchie, of Boston, in 1856, and makes eighty-five turns in each disk. The coil is accompanied by a Foucault circuit-breaker, and gives a spark in the air of fifty centimeters (twenty inches) in length. In an exhausted tube the spark passes ten meters. It charges instantaneously a battery of four square meters of coated surface.

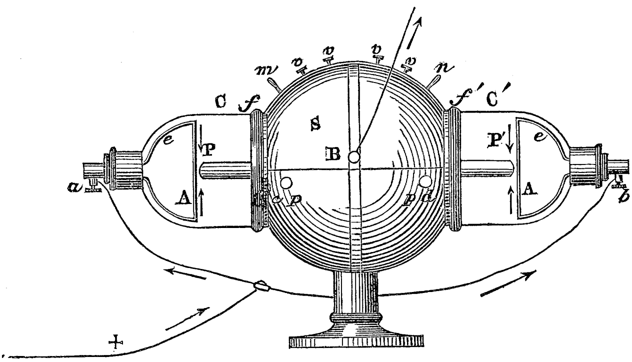
Geissler's tubes were exhibited in great variety and beauty by Messrs. Ruhmkorff, Alvergniat, Gaiffe, and Seguy; and also at a late period by Geissler himself. Though there were many novel patterns, the apparatus itself presented no points of novelty, unless an exception be made in the case of the miners' electric lamps, which are simply Geissler's tubes adapted to a useful and an important purpose. These lamps are recommended by their entire safety, and by the fact that they require no trimming.

DE LA RIVE'S AURORA BOREALIS.

The most interesting of all the forms of apparatus exhibited, designed to illustrate the relations of light to electricity, was a combination presented by the society for the construction of physical apparatus of Geneva, and invented by Mr. De La Rive, in which are reproduced in miniature all the most striking phenomena of the *aurora borealis*. This apparatus consists of a hollow sphere of wood, designed to represent the earth, which contains an electro-magnet occupying the position of

the axis, while the polar regions are crowned by two bell-glasses fixed air-tight to the sphere. The arrangement is shown in Fig. 119, in which

Fig. 119.



De la Rive's Auroral Apparatus.

B is the sphere, supported on a foot, and C C′ are the bell-glasses. These bells are attached to the sphere by two rings of metal indicated by the letters *f f′*. At *a* and *b* are stop-cocks, which permit the bells to be exhausted by communication with an air-pump. The electro-magnet is concealed within the sphere, the soft iron core reaching only to the plane of the circles *f* and *f′*; but it is lengthened by means of two soft iron cylinders of similar cross-section, which are insulated from it by interposed plates of mica. These cylinders, marked P and P′, are in metallic communication with the corresponding rings *f* and *f′*. From each of the two stop-cocks proceeds a stirrup-shaped wire, *e*, which carries a ring, A, of brass gilded. The sphere is surrounded by an equatorial circle of brass, which carries a connecting screw at B. In the meridional direction from one of the rings *f* to the other, there passes over the top of the globe an imperfectly conducting band, formed of a composition of black lead and sulphur. This is not in immediate contact with the rings, but may be connected with them by means of two springs or switches of brass, operated by buttons of ivory at *m* and *n*. On the under side there is another band made of thick paste-board, which, when dry, is non-conducting, but which is converted into an imperfect conductor by being moistened with a saline solution. Several binding screws *v v* are attached to the superior meridian, for the purpose of connecting a galvanometer with the apparatus, in order to illustrate the effects of the aurora upon the magnetic needle.

In experimenting with this apparatus, the bell-glasses are first exhausted, after which communication is made from the binding screw B to the negative electrode of a Ruhmkorff coil, while the positive electrode has a double connection, as shown, with the stop-cocks *a* and *b*. A continuous discharge is kept up from the coil by means of an automatic circuit breaker. The luminous jet then makes its appearance in the bells as marked by the arrows. The light is equal in the two bells only on condition that the resistance in the two circuits is equal, a case which rarely occurs. It may be thrown into one or the other at pleasure by opening and closing alternately the interruptors at *m* and *n*. In this state of things, if the electro-magnet within the sphere be put

into communication with its battery, the jet spreads itself out and takes at once the form of a luminous shell.

In illustrating the influence of vapors upon the aspects of the light, the connections are differently arranged. The positive electrode of the coil is connected with the stop-cock *a*, the ring *f* with the stop-cock *b*, and the ring *f′* with the negative electrode. The exhaustion of the bell-glasses is carried as far and is made as equal as possible. On passing the induced current of the coil, and exciting the electro-magnet, the jet will appear in both bells, and will assume a motion of rotation around the poles P P′, changing its direction whenever the current is reversed. The jet appears sometimes single and sometimes divided into several minor streams. If a minute quantity of water be now admitted to one of the bells, which may be done by means of a stop-cock provided for the purpose, the effect of the vapor thus produced upon the appearance of the light is instantaneous, and recalls the well known form and movements of the columnar aurora.

The influence exerted by the aurora upon the magnetic needle is illustrated by connecting the communicating wires of a galvanometer with any two of the binding screws *v v* during the progress of the experiment. The galvanometer is placed so far from the apparatus as to be beyond the reach of any direct influence from the electro-magnet; but as the superior meridian is imperfectly conducting, the derived current from *f* to *f′* will traverse the coil rather than follow the more direct route, and the needle will be deflected, thus showing artificially the effect which the natural aurora always produces. By interrupting the upper current at *m* or *n*, and moistening with the saline solution the pasteboard meridian band of the lower hemisphere, similar effects may be shown on that side also.

ELECTRO-CHRONOSCOPES.

The application of electricity to the determination of minute intervals of time has contributed materially to the exactness of results in a number of important departments of scientific observation. Illustrations have already been given of the manner in which experimental investigations in acoustics have been facilitated by electrical methods of maintaining vibrations. In astronomy the introduction of the electrical method of recording observations has been a source of still higher advantage. Thirty years ago one second was the smallest interval of time for which astronomers possessed an exact instrumental measure. Intervals less than seconds were merely estimated; that is to say, guessed at, the judgment of the observer being assisted by the apparent motion of the object observed across the lines of his instrument. The introduction into astronomical observatories of the electro-chronograph first suggested by Professor Locke, of Cincinnati, constituted an important era in the history of practical astronomy.

The study of the flight of projectiles is another branch of experimental inquiry which has been greatly aided by electro-chronographic methods. The earliest observations on the velocity of cannon balls were made by means of mechanical contrivances which, though exceedingly rude, were for fully a century the only means known of attaining or approximating to the knowledge sought. These were the ballistic pendulum of Robins, and the gun-pendulum of Rumford.

To Professor Wheatstone belongs the credit of having first suggested, in 1840, the use of electricity to mark the instants of time in which a projectile passes in its flight two determinate points, and of thus deducing the mean velocity with which it describes that portion of its trajectory. His apparatus consisted of a revolving cylinder, upon which rested lightly, a tracer, describing, as the cylinder turned, a mark upon its surface. When the instrument was prepared for experiment, this tracer was retracted by the influence of an electro-magnet. Two wire targets, or screens, were placed at suitable distances before the gun, and were so connected with the electrical circuit operating upon the magnet that, as the projectile passed the first, this circuit was broken, and as it passed the second, the circuit was re-established. With the rupture of the circuit the tracer fell upon the cylinder, and it was instantly withdrawn again on the renewal of the current. The velocity of rotation of the cylinder being known, the length of the line traced during the brief interval between these two incidents became an indirect measure of the velocity of the projectile.

In 1843, Professor Henry, of Princeton, now Secretary of the Smithsonian Institution, a physicist whose name is inseparably associated with the history of electrical discovery, presented to the American Philosophical Society a paper in which he proposed to mark on the surface of a revolving cylinder, by means of the intense secondary spark of an induction coil, the instants in which an electric circuit is ruptured by a projectile. This was the first suggestion of an expedient which many inventors have since adopted, and which is employed in the most remarkable of the electro-chronoscopes exhibited in the Exposition, that of Captain F. P. E. Schultz, of the imperial artillery of France.

The first electro-chronoscope proper, however, in the order of invention, was that of Captain Navez, of the Belgian artillery, called by him, from the peculiarity of its construction, the electro-ballistic pendulum. This is, as its name implies, a pendulum, having a length of only a few inches, and traversing in its swing a graduated semicircular arc having its center at the point of suspension. The pendulum carries with it an index, which may be stopped in the descent at any point of the scale, by the action of an electro-magnet behind the instrument, without arresting the pendulum itself. When prepared for experiment the pendulum is raised to the horizontal position, the index being coincident with it, and is held there by another electro-magnet. As the projectile breaks the wire of the first screen the pendulum falls. Before the swing is completed the

the second wire will be broken; and this rupture of circuit determines the action of the electro-magnet which stops the index. Here, however, the action of the instrument is a little complicated. The immediate effect of the breaking of the second wire is merely to drop a little weight. It is the fall of this weight which closes the circuit of the second magnet and stops the index. The division on the scale at which the index is stopped will give, from the known law of acceleration of the pendulum, the time which has elapsed from the commencement of the swing. But this time embraces not only that occupied by the projectile in passing from screen to screen, but in addition to this the time of the weight in falling. The latter term, however, is a constant, and it is eliminated by means of a preliminary experimental determination of its value, made by breaking the circuits of both magnets at once, and so dropping both pendulum and weight in the same instant.

The pendulum of Captain Navez did much to advance the science of ballistics; but it was objected to it that the release of a body suspended by an electro-magnet is not instantaneous; so that neither the pendulum nor the weight begin to fall in the instant of the rupture of the circuits of their respective magnets. It was further alleged as an objection that it is too delicate and too complicated for general use.

In 1859, Major (now Lieutenant Colonel) James G. Benton, of the ordnance department of the United States army, constructed an electro-ballistic pendulum of a simpler description. In this there are two equal pendulums suspended one behind the other from the same center of motion, and traversing also, as in the case of that just described, a semicircular divided arc. The pendulum nearest the arc has a movable point directed toward the arc; and the outer one carries a projection suited to drive this point against the limb as the two pass each other in the swing. When the instrument is prepared for use, the two pendulums are brought both to the horizontal position, and suspended by electro-magnets at opposite extremities of the semicircle. A paper is also attached to the limb to receive the mark of the point. The pendulums are successively released by the rupture of the circuits of the magnets sustaining them as the projectile passes the two screens; and the mark left at the point of meeting serves to ascertain the difference between the times of release. In order that the indications of this instrument may be trustworthy, it is necessary to be assured that, when the two pendulums are simultaneously released, they meet accurately in the middle of the limb, or at the point of lowest descent. It has been objected to Captain Benton's pendulum, as to that of Captain Navez, that the retardation of the moments of release on account of the persistency of magnetism in the soft iron cores of the electro-magnets, renders the indications in a measure uncertain; but the instrument has performed remarkably well in experiments made with it by ordnance officers in the United States service.

The secondary spark from the induction coil originally suggested, as

above mentioned, by Professor Henry, for this use, is believed to have been first actually introduced as a substitute for the mechanical mode of marking, by Captain Martin de Brettes, of the French artillery, in 1858. At an earlier period (1854) Captain Siemens, of the Prussian service, had proposed, for the same purpose, the spark of the Leyden jar. Captain Siemens employed in his experiments a polished steel cylinder rotating uniformly, on the surface of which the spark in passing produces a visible tarnish. Captain de Brettes at first applied his method to a pendulum, which discharged sparks upon the graduated limb before which it swung. He subsequently employed a body falling directly, in guides, in front of a plane surface, the sparks passing to this surface from the falling body in different parts of its vertical trajectory; and he finally adopted the revolving cylinder in preference to either of the other expedients, as permitting a greater protraction of the experiment. The cylinder is, in fact, indispensable, in case a projectile is to be followed up throughout its entire trajectory, or even for any considerable part of it; since the duration of the swing of the pendulum, or of the direct fall of a body through any distance admissible into the apparatus, can only amount to a fraction of a second. A cylinder, however, revolving on a helical axis, which advances it slightly in the direction of its length at every revolution, permits a continuation of the observation through any desirable length of time.

The form of chronoscope upon which Captain de Brettes has finally settled down is exhibited in the Exposition by Mr. E. Hardy, of Paris, by whom it was constructed under his direction. He still inscribes his record on a cylinder, but he chooses that the cylinder shall remain fixed, while the marker revolves around it. The cylinder has a vertical position, and is divided on its cylindrical surface by lines parallel to the axis into one thousand equal parts. The marker travels round it three times per second. In the mean time a strong mechanism of clock-work causes the cylinder gradually to descend, while the marker moves always in the same horizontal plane, and thus the marks made in different revolutions are kept distinct from each other. The revolution of the marker is produced by a conical pendulum which surmounts the whole apparatus. This is driven by clock-work and requires no escapement, the revolution, which is completed in one second, being entirely uniform. The driver which maintains the motion of the pendulum might also, if thought expedient, carry the marker; but an intermediate gearing is interposed in order to increase the velocity and produce three rotations per second instead of one. It follows, of course, that the arm carrying the marker must bend at right angles and descend vertically at least far enough to deliver its sparks at the lower margin of the cylinder when that is at its highest point.

In the earlier experiments of Captain de Brettes with the Ruhmkorff coil he employed paper as the material on which to receive the sparks. But the punctures made by the spark in paper are so minute and so

difficult to find, that, like Captain Siemens, he resorted subsequently to metallic surfaces. The cylinder in the instrument actually exhibited is made of bronze, and is silvered by galvanism on its cylindrical surface. Silver has the advantage over steel, which was the metal used by Captain Siemens, in being much more easily repolished after being spotted by the sparks. No information was obtained as to the performance of this instrument.

In the Exposition are exhibited electro-chronoscopic instruments by three inventors, besides Captain de Brettes. The Belgian section contains several very ingenious forms of this apparatus, by Professor M. Gloesener, of Liege. In one of these a plane surface is made to fall vertically under the influence of gravity, while marking points held in check by electrical attraction fall on it at intervals as their circuits are broken. In another, the pendulum principle is adopted; but the whole limb swings and the markers fall on it as in the case just described. In a third there is employed a uniformly rotating cylinder with several markers in front of it, permitting several successive marks to be made during the same experiment. This cylinder is governed by a Foucault regulator, the efficiency of which contrivance has been elsewhere mentioned. A special merit of Professor Gloesener's instruments is that the possible error arising from persistency of magnetism, which renders the indications of several of the instruments above spoken of more or less uncertain, is entirely eliminated. Professor Gloesener's markers are not connected with soft-iron armatures controlled by electro-magnets, but they are magnetic bars of steel, surrounded by galvanic multipliers; that is to say, they are substantially galvanometer needles. Each one carries at its extremity a small hollow cone with a minute perforation at the summit, into which is introduced some suitable marking liquid. The needles start instantly when the circuits are broken, and the time of fall is the same for every one. This can be verified by dropping them all together.

In the French section is exhibited the electro-chronoscope of Captain Schultz, already mentioned. In this machine a cylinder of rather large dimensions (one metre in circumference) covered with paper, which is afterwards coated with smoke as for the experiments heretofore described in acoustics, is designed to receive the marks made by the sparks of an induction coil as the projectile breaks the successive circuits. Close by the side of the point which delivers these sparks is a diapason carrying a light tracer, which rests on the cylinder and produces there, when the instrument is in operation, a continuous mark. The cylinder turns on a helical axis, so that if it be permitted to run while the diapason is at rest, the mark left by the tracer will be a uniform and smooth spiral; but if the diapason be put into vibration, the spiral becomes sinuous or dentelated. In preparing for experiment the smooth spiral is first obtained, and then the instrument is set back to the original starting point. The diapason being provided with the electro magnetic apparatus

for maintaining vibration, described in the article on acoustics in this report, is first excited by mechanical means. The automatic interruptor then immediately takes effect and continues the vibration until the circuit of its controlling electro-magnet is broken. As the cylinder turns, the sinuosities of the path described by the tracer cross the mean line in the middle of every simple vibration, and establish so many exact points of reference for the determination of time. The diapason makes one thousand vibrations per second and the cylinder makes three turns in the same time.

There is a peculiarity in the construction of the screens used by Captain Schultz, which requires mention. The wires are attached at their upper extremities to metallic springs and hold these springs just out of contact with a metallic plate above them. The space of separation is very minute, and the moment a wire is broken its spring strikes the plate. The rupture of the wire causes the spark to pass in the instrument, but the contact of the spring with the plate, which almost instantaneously follows, closes the circuit for the next screen, so that when the projectile reaches that, a second spark passes. The current is then closed in the same way for a third screen, and again for a fourth, and so on. The Schultz electro-chronoscope has been used by officers of the United States ordnance service with very satisfactory results.

The fourth exhibitor of electro-chronoscopic apparatus is Professor F. Bashforth, of Woolwich, England. Professor Bashforth uses a cylinder to receive the indications; but these indications are permanent marks made by hard points on a glazed paper covering the cylinder. The axis of the cylinder is vertical, and at its lower extremity it passes downward through the base of the apparatus, which has the form of a tripod. A heavy horizontal fly-wheel is attached to it here, which, when the instrument is to be used, is put in motion by the hand. As the friction is small and the mass of the fly considerable, the rotation is sustained for some length of time with sensible uniformity. The accuracy of the time measurements is not, however, dependent on the permanent uniformity of rotation, since marks from a clock beating seconds are recorded at every beat, precisely in the same manner as in the well-known astronomical chronograph of Bond; that is to say, a point, which traces in the intervals between the beats a continuous line, suddenly starts aside as the clock contact is made; that is to say, at the end of every second. In Professor Bashforth's apparatus there are two markers side by side, one making a mark every second and the other marking at every rupture of a circuit by the projectile. The circuits when broken are re-established in the same manner as in the Schultz screens. There is one further difference between the two contrivances last mentioned, which relates to the mechanical arrangements. In the Schultz instrument the cylinder advances in the direction of its length. In that of Professor Bashforth the cylinder has no longitudinal move-

ment, but the markers are carried by a frame which moves vertically in guides, and which, by a pulley arrangement, is allowed to descend slowly by its own weight as the cylinder turns. The result is, as in the other case, that a fresh portion of the cylinder is brought under the markers at every revolution.

VII.—METEOROLOGY.

To however greater or less a degree a scientific visitor to the Exposition might have been disappointed in his search for interesting novelties, one fact he could not have failed to notice as evidencing remarkable progress in recent years, which is the singular development given by later observers in meteorology to apparatus designed for the automatic registration of the varying conditions of the atmosphere. The truth seems to be every day more and more distinctly recognized that the system of meteorological observation heretofore pursued is entirely inadequate to the discovery of the laws which govern atmospheric changes. This system has been long in operation. It has been faithfully and patiently followed up at a multitude of stations scattered all over the surface of the habitable world. It has drawn heavily upon the time and strength of many able men and earnest devotees of science, and it has accumulated a mass of recorded observations of the humidity, temperature, pressure, and movements of the air so great, that it would seem as if it must suffice to the discovery of everything which it will ever be possible for man to discover in regard to the causes affecting these phenomena. At some of these stations the records thus gathered have been printed for the general use of the scientific world. At many, they have become so voluminous that the inquirer who desires to extract from them the evidence of law which they are presumed to embody, is embarrassed by the abundance of his material and disheartened by the intolerable tediousness of his task. A record, while it stands in the form of a succession of numbers, teaches nothing. Even the combination of the numbers which are recorded under the present system at our numerous meteorological observatories, however variously and laboriously made, teaches little. The mean pressure, the mean temperature, the mean velocity of the wind, &c., at a given hour of the day at the station, for the year or for the month, may be ascertained, and the extreme limits of the fluctuations may be detected. This may be done, perhaps, for several selected hours of the day. But the oscillations about these means cannot be clearly presented to the mind in any other way but by projecting all the observations into the form of curves. The process is inexpressibly wearisome, and the result after all is comparatively valueless; for the fluctuations of atmospheric condition are continually going on, while our observations periodically made touch them only momentarily here and there at a few isolated and widely separated points.

The observations of the several instruments in meteorological observatories generally are made four times a day; in some perhaps, but

certainly not in many, more frequently. But even if they were made hourly they would still be discontinuous, and would still be recorded in the numerical form; a form which, however conducive to the exactness of absolute determinations or convenient for the uses of calculation, conveys to the mind no clear conception of the nature of the changes which are proceeding, and no clue to the laws which govern them. The system of meteorological record heretofore almost exclusively pursued is defective, therefore, in this, that as to time, it is limited to observations which are intermittent and periodical; and as to form, it embraces only the scale readings at the moments of observation of the several instruments set down in numbers.

A system is therefore needed in which the registration of the instrumental indications shall go on incessantly, and shall furnish a record of the fluctuations of atmospheric condition which shall be absolutely unbroken; while at the same time these fluctuations are expressed explicitly and graphically in the form of curves, rather than by obscure implication in columns of numbers. Such a system can only, of course, be carried into effect by means of automatic instrumental registration.

The extent to which this necessity is at present recognized is made evident by the number and variety of forms of self-registering apparatus for the observations of meteorology which have been brought forward in the Exposition of 1867. All of these instruments are ingenious; many of them are admirable. Their general introduction into observatories will do much to remove from the science of meteorology the reproach which has long rested upon it of being a barren science—a science which exacts more of its votaries than any other, and returns them less.

But there is a second defect of the system of meteorological observation and record in common use, against which the ingenious inventors whose instruments are here exhibited have not in every case been careful to make adequate provision.

This is found in the extent to which the records of the different instruments are commonly kept independently of each other; so that the relations which connect fluctuations of atmospheric conditions of different kinds, or the degree to which these are mutually influential, are kept out of view, or are at least not made purposely and prominently conspicuous.

We occasionally even see curves which have been elaborately projected from observations of the thermometer, the barometer, the psychrometer, and the anemometer, made at our principal observatories, presented on sheets entirely separate, as if the phenomena recorded by each of these instruments were without natural connection with the rest, and were possessed of an interest quite special and peculiar; but it is obvious that if we ever arrive at any better knowledge of the laws regulating the weather than we have yet attained, it will only be by studying the weather as a whole, and carefully considering what changes in each class of atmospheric conditions have a necessary connection with other changes simultaneously going on in every other class.

The system, therefore, of meteorological record which we need, is one in which every class of fluctuating atmospheric conditions shall be graphically recorded, and in which the curves of record shall be in immediate juxtaposition upon the same sheet. We shall then have a complete picture of the weather delineated by the hand of nature herself; and the study of the mutual relations of its different phenomena will be reduced to the last degree of simplicity possible in a problem of so difficult complication.

The importance of this consideration appears to have been appreciated by some of the exhibitors whose instruments for automatic meteorological registration have been referred to above; but in none of these forms of apparatus has the object here indicated as so desirable been realized in a manner so entirely satisfactory, as in the *météorographe* exhibited by Father Angelo Secchi in the section of the Pontifical States.

Several of the registers exhibited were confined in fact to the object of recording the indications of a single instrument exclusively. Thus, wind-registers were presented by Mr. Beck, of London, Mr. Hervé-Mangon, of Paris, and Mr. Parnisetti, of Italy; temperature registers by Mr. L. Jean, of Vienna, and Mr. A. G. Theorel, of Upsal, Sweden; pressure-registers by Mr. Breguet, of Paris, &c; while of the exhibitors who aimed to extend their provisions to a larger number of the atmospheric phenomena, only a few had so arranged their constructions as to permit the several records to be inscribed on the same sheet. Thus, Mr. Hipp, of Neuchatel, Switzerland, exhibited a *barographe* and a *thermographe;* Mr. Gros-Claude, of Geneva, registers for the barometer, thermometer, and hygrometer; Messrs. Hasler & Escher, of Berne, registers for the barometer, thermometer, pluviometer, and anemometer, &c. These last very ingenious instruments were constructed under the direction of Professor Wild, director of the observatory of Berne and professor of physics in the university of that city. A single regulating clock determines the advance of all the register sheets at a common rate; so that these may be assembled side by side for purposes of comparison. A registering apparatus by Mr. J. Salleron in the French section records, in parallel divisions of the same sheet, the direction and velocity of the wind, the height of the barometer, and the fall of rain. In all the instruments above named, the mark is made by the action of electro-magnets, of which the circuit is periodically closed by clock-work. Most of them require a new sheet of record to be introduced daily; but the apparatus of Professor Wild is adapted to receive, in the form of a roll, a sufficient amount of paper to last for many days or even weeks; and during this time it requires no attention except to wind up the clock at the end of every eight days, and to see that the battery remains in good condition.

By far the most interesting and the most important of the self-registering meteorological instruments exhibited is the *météorographe* above mentioned, by Father Secchi. This instrument, apart from its scientific

interest, has excited much admiration for its elegant proportions, its superior workmanship, and the beauty of its finish. Its height is seven or eight feet, upon a base about six feet by two. The lower portion is inclosed in polished mahogany; the upper is glazed, and contains the apparatus of registration. Surmounting the whole is an elegant clock, which regulates the motion of the tablets on which the registration is made. Of these there are two, one occupying each of the broad faces of the instrument. The clock also regulates the movements of many subordinate parts of the apparatus.

The object of employing two tablets is not to register a portion of the recorded phenomena on one and the rest on the other, which would be a violation of a principle regarded by Father Secchi as of the highest importance, viz: the presentation of a complete system of records side by side; but it is to obtain records on different scales, of which the larger will permit a better examination of the details of the variations, especially when these are sudden and violent, while the less brings them into more compact form and facilitates comparison. The sheets are of a size suited to a large portfolio; and as they are removed from the instrument, they are preserved in their order and are periodically bound. As the *météorographe* has been for eight years in operation in the *Collegio Romano*, at Rome, its records form now quite a series of volumes, some of which, by the courtesy of Father Secchi, the reporter has been permitted to examine. No one from an inspection of these records could fail to be strongly impressed with the evidence they present of the importance, in the study of meteorological questions, of having all the elements of the problems involved placed side by side.

The tablet on the principal face of the instrument gradually descends, under the action of the clock, and completes its course in two days and a half. The one on the opposite side occupies ten days. The sheets of paper on which the record is received are faint-lined in red both vertically and horizontally; the divisions on the vertical sides indicating time, and those on the upper and lower borders the instrumental readings.

The first face, devoted to records on the larger scale, gives the indications of the barometer and of the wet and dry thermometer, but omits the winds, which are sufficiently represented in the *resumé* of all the phenomena on the other side. The barometer is the balance barometer invented by Father Secchi himself in 1857, though, as he states, he has since discovered that something of the same kind had been suggested about two hundred years ago by Moreland, though apparently never used. The tube is of forged iron, bored very truly cylindrical to a diameter of two centimeters; but the superior part has a bore of six centimeters, in consequence of which the fluctuations of the mercurial column occasion greater differences of weight than would occur in a uniform bore, and thus render the instrument more sensitive. The lower extremity of the tube is embraced by a cylinder of wood, which, plunging into the reservoir of mercury, sustains the principal part of the weight of the

instrument, and reduces very much the pressure on the pivot of the balance. The oscillations of the balance are communicated, by an ingenious system of levers, to two pencils, by which they are recorded on both tablets at the same time, on a scale of enlargement of one to four and a half.

Two mercurial thermometers, of which the tubes are open at the top, furnish the indications for temperature and humidity. At the bottom of each of these tubes a small platinum wire fused into the glass makes metallic communication with the mercury in the interior. The bulb of one of them is dry; that of the other is covered with muslin kept constantly wet. Into the open tubes of the thermometers are introduced the extremities of two wires of platinum connected with a slider which periodically descends, causing the wires to make contact with the mercury in the tubes. The descent of this slider is produced by a lever system connecting it with a little car running on a railway before the tablet of record. At the end of every fifteen minutes the clock puts in motion a mechanism which causes this car to run along the railway operating the levers which cause the slider to descend. The car carries also a pencil directed toward the tablet. As the slider descends, it will be the dry bulb thermometer in which the entering wire will first make electric contact. At the instant this occurs the pencil falls on the tablet and, in the further advance of the car, it traces a line which continues unbroken until the moment when contact is made in the wet bulb thermometer. The circuit closed by this contact operates a magnet which breaks the circuit of the first, and the pencil is immediately retracted. The car after having completed its course immediately returns, and the pencil marks, a second time, in returning, the trace it had made before.

The hour of rain, and the duration of the rain, are marked upon this face of the instrument by means of another pencil controlled also by an electro-magnet. The circuit of the magnet is opened and closed by a little water-wheel placed under a water conductor in any convenient situation within or without the building. The *quantity* of water falling cannot be thus registered. This determination has to be made by a special contrivance. At one side of the instrument near the top is a disk of eight or ten inches in diameter, turning on an axis which carries also a pulley, over which passes a chain. One end of this chain carries a weight, the other is attached to a vertical stem proceeding from a float in a reservoir in the base of the instrument. The water from the rain gauge is conducted to this reservoir, causing the float to rise; and this necessarily causes the disk to turn. To the solid disk is attached a corresponding disk of paper, and upon this paper rests the point of a pencil, which has a gradual motion outward from the center at the rate of about five millimeters a day. If in the meantime there is no rain, the disk will not turn, and the mark of the pencil will be a radial line. But should rain occur, the trace will become a circular arc, or strictly speaking, a spiral; and the amount of angular rotation will be a measure of

the quantity of rain fallen, which, however, is also indicated on a vertical scale by an index carried by the vertical stem of the float.

On the other face of the instrument are recorded the indications of the barometer, as just mentioned, and also those of the hours of rain and those of the thermometer; but this time it is not the mercurial thermometer of which the indications are registered, but a very simple metallic thermometer formed of a stretched copper wire. This wire is stretched in some place where the temperature represents the temperature prevailing in the shade at the time, and the variations of its length are transferred to the tablet by mechanical means entirely, the magnitude of the movement being enlarged in any desired proportion. Father Secchi states that this thermometer will give indications to one-quarter of a degree centigrade.

There remain to be described the modes of registration of the direction and the velocity of the wind. The directions of the wind are recorded by four pencils resting on the tablet, and attached to as many levers having a limited lateral oscillation as they are acted upon from time to time by electro-magnets in communication with the wind-vane and the anemometer. There is a pencil for each of the cardinal points of the compass, and each has its separate electro-magnet. All these magnets have their bobbins in an electric circuit passing through the wind-vane and the anemometer, which is therefore so far common to them all. The anemometer, which is the cup-anemometer known as Robinson's, closes the circuit once in each revolution. On the other side each magnet has a separate circuit which communicates with a metallic quadrantal arc corresponding to the point of compass to which it belongs; all the four quadrants being assembled to form a circle surrounding the rod of the wind-vane, but being insulated from each other. The wind-vane carries a tongue of elastic metal which traverses the circle just spoken of, and which, at every turn of the anemometer, closes the circuit for one at least of the magnets, and accordingly puts one at least of the pencils above spoken of in motion. If the tongue happens to rest on two quadrants at a time, at their junction, or if by oscillation it passes rapidly from one to the other, two pencils may be operated at once. This will indicate a wind intermediate between the cardinal points corresponding to these two pencils. It will be seen that the distinction of the directions of the winds is not very nice. Father Secchi remarks, "Experience proves that, in practice, this system satisfies the wants of meteorological science in its actually existing state." This is the only remark of his on the subject which is likely to be accepted with hesitation.

The apparatus for registering the velocity of the wind is somewhat complicated. At the top of the instrument, on the side opposite to the principal dial of the clock, are placed a number of counting dials, by means of which an actual register can be made in kilometers of the whole space the wind may be presumed to have passed over during a determinate period. The first of these counters is set forward one tooth

at every revolution of the anemometer, by means of an electro-magnet. This is all that it concerns us to consider, in describing the mode of registration on the tablet. Upon the axis of this first counter there is a pulley on which is wound up gradually a little chain. This chain, through a system of levers, draws in a horizontal direction a pencil resting on the tablet. As the counter turns slowly, the pencil advances very gradually along the paper; but the rapidity of its progress, and the extent of its progress in a given time, are necessarily dependent on the velocity of the wind. At the end of each hour the pulley is suddenly set free on the axis of the counter, and as the pencil is always acted on by an opposite weight resisting its advance, it immediately runs back to the starting point; after which the pulley becomes locked again, and the operation is renewed. The length of the line traced in each hour becomes thus a visible measure of the mean velocity of the wind during the same time.

This very brief and imperfect account of one of the most ingenious combinations of mechanism to effect a purpose of great practical utility and of extreme interest to science which the Exposition embraces, or which has been produced in recent years, may serve to convey some idea of the advantage which would be likely to accrue to the progress of meteorology could so efficient a mode of representing its phenomena be introduced into observatories generally. There is nothing but the expensiveness of the apparatus to prevent; but that, unfortunately, is considerable. For an instrument of the same finish and elegance as the one exhibited in the Exposition, the constructor, Mr. Brassart, of Rome, states the price at eighteen thousand francs. For a more modest model, such as is actually used in the observatory of the Collegio Romano, containing all the registration apparatus complete, it is ten thousand francs. But for a simplified *météorographe* provided with only the ten-day tablet, and with cabinet work entirely plain, it is as low as three thousand. These prices will prevent the introduction of the instrument into any but well-endowed institutions, and will be likely to operate its exclusion from the minor observatories altogether.

CHAPTER XVII.

GEODESY AND NAVIGATION.

METHOD OF MEASUREMENT IN SURVEYING—TELEMETRIC METHODS—ROCHON'S DOUBLE REFRACTION TELESCOPE—LORIEUX'S BINOCULAR TELEMETRIC GLASSES—THE STADIMETER—PORRO'S STENALLATIC TELESCOPE—DIVIDED OBJECT-GLASS TELESCOPE—DIVIDED EYE-GLASS TELESCOPE—TELEMETRIC DOUBLE TELESCOPES—BALBRECK'S DOUBLE TELESCOPE REFLECTING TELEMETER—ELECTRIC TELEMETERS—PRISM TELEMETER—TELEMETRIC SINGLE TELESCOPES—THEODOLITES—DABBADIE'S TRAVELING THEODOLITE—LEVELING INSTRUMENTS—PISTOR AND MARTEN'S SEXTANTS—LAURENT'S—DAVIDSON'S—NAUTICAL COMPASSES—WEDEL-JARLSBERG'S—RITCHIE'S—DEEP-SEA SOUNDING—TROWBRIDGE'S DEEP-SEA APPARATUS—MORSE'S BATHOMETER.

I.—TELEMETRICAL APPARATUS.

The simplest mode which suggests itself for determining the distance between two points of the earth's surface is to apply a measure of known length along the line connecting them. This is the method used in common surveying. It admits of a near approach to accuracy when the inequalities of the intervening ground are inconsiderable and the measuring instruments accurate. But great care and skill are necessary, even under these circumstances, in order to preserve the line direct and to insure the commencement of each successive measurement from the exact point at which the last one ended. Over broken ground, water-courses, lakes, and mountainous districts, direct measurement is always attended with great difficulties, and is often impracticable. For geodetic operations of importance it is therefore usual to call in the aid of trigonometry. Direct measurement is indeed still necessary, even in this case, in order to establish a base for the commencement of operations; but the ground on which this base is measured may be chosen at pleasure, and need not even be in the vicinity of the line or the surface of which the dimensions are required. After the base has once been measured—a process which in large works of geodesy is a very small part of the whole, and one which may therefore be executed with all necessary care and deliberation—the remaining field-work is reduced to the observation of angles; in the performance of which, instrumental accuracy has been carried to an extraordinary degree of refinement.

There are many purposes, however, for which it is desirable to ascertain the distances between points visible from each other, with something less than absolute accuracy, yet more accurately and more expeditiously than they can be directly measured. To accomplish this object a variety of instruments have been devised, some of them displaying remarkable

ingenuity. In the collection of astronomical and geodetical instruments exposed by Messrs. Brunner Brothers, of Paris, were embraced several of these.

When an object at a distant station and visible to the observer is of known dimensions, the problem presents comparatively little difficulty. Any instrument by which angles may be accurately measured will suffice to resolve it. If the two stations are on the same level, it will only be necessary to measure the angle at the observer's eye subtended by the object; and this being ascertained, a triangle will be given in which all the angles and the base are known. If the stations are not on the same level it will be necessary additionally to measure the angle of elevation or depression of the object observed. The distance sought, however, can only be found by this process by means of a solution of the triangle obtained as above, and this involves a somewhat troublesome numerical operation. The necessity of such a calculation may be avoided by the preparation of tables in advance in which angles may form the *arguments* or entering numbers at the side, while the various possible linear dimensions of objects observed may furnish the arguments at the top. The distance corresponding to any given object and angle may then be found by inspection. It is convenient, nevertheless, to be relieved of even the necessity of consulting tables, and this may be done by graduating the instrument itself in such a way that, after any observation, the index shall point to a number telling how many times the distance is greater than the object. Suppose, for instance, that with such an instrument an object ten feet in height or in breadth is observed, and that the index marks the number 528. The distance of the object will then be 528 times ten feet, or 5,280; that is, one mile.

ROCHON'S DOUBLE-IMAGE TELESCOPE.

Rochon's double-image telescope is an instrument of this kind; that is to say, its indications multiplied by the known diameter of the object give the distance; but it is not what we have been supposing above, an angle-measuring instrument. The two images which this telescope gives of the same object are produced by a doubly-refracting prism of Iceland spar within the barrel of the instrument, which divides the converging pencil of rays into two pencils deviating from each other by a determinate angle. Two images are therefore formed by these pencils after their deviation; and it is evident that their separation from each other will be greater the farther they are formed from the prism. When the distance of the object is given, the distance of the image from the object-glass is of course fixed; but the prism is movable, and by means of a rack and pinion it may be transferred from one end of the tube to the other. On observing the object through the telescope, if the images overlap, the prism must be moved farther toward the object-glass. If, on the other hand, they are separated by an interval, it must be drawn

toward the eye-glass. When the two images are in exact contact, the index on the slide which carries the prism points on the exterior of the barrel of the telescope to the number denoting the distance. It is evident that, inasmuch as the size of the image is less as the distance is greater, the numbers marked on the barrel must increase from the object-glass in the direction of the eye-glass. Such an instrument may be graduated by the indications of theory, but it is safer to determine the scale by trial.

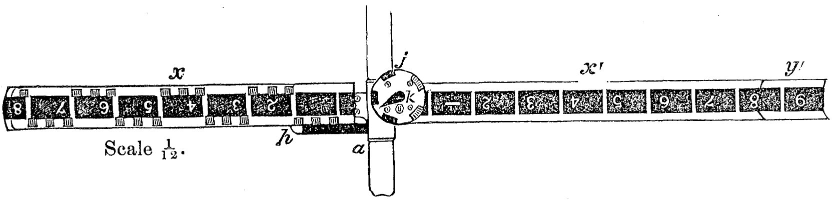
BINOCULAR TELEMETRIC MARINE GLASSES.

Mr. Lorieux, of Paris, exhibited a binocular marine glass, designed to determine distance by the measure of the angle subtended by a known object; and this means by a construction which permits the axes of the two tubes to be thrown out of parallelism by an angular movement around an axis joining the two eye-pieces. The effect of this movement is to double the image of an object which appears single when both axes are in the same plane. One of these images will appear directly over the other, and when they are in contact by their edges, the angular movement of one tube which has been required to produce this effect will be, of course, equal to the angle subtended by the object at the eye of the observer. Before making an observation the instrument should be adjusted to show but a single image of some sharply-defined object, and any error of adjustment of the index on the scale should be corrected. Another instrument, also binocular, exhibited by the same optician, was designed to determine distances by a simpler means. It has been a plan frequently adopted in instruments of this class to introduce a micrometer, with movable lines, into the focus of the object-glass of a telescope, observing by means of a Ramsden eye-piece. The size of the image decreasing as the distance increases, the measure of its diameter becomes indirectly a measure of distance. The eye-pieces of marine glasses being negative, there is no real image formed within the tube, and hence a micrometer cannot be employed with such a glass. But by interposing in front of the object-glass an opaque body, as a plate of metal, the field of view can be reduced; and thus, in effect, the varying breadth of the field may be made to subserve the purposes of a micrometer. If a vertical plate be interposed on each side of the axis and the two be made to approach and recede symmetrically, by means of a screw, right-handed on one side and left-handed on the other, they may be brought to include between them any object of known dimensions; and as, when the object is near, the opening must be wider to allow of this than when it is more distant, the instrument becomes a *telemeter*, or distance measurer. For facility in use it is more convenient in general that the edges of the plates should be horizontal than vertical; but either construction may be employed. The principle here explained is that which has been adopted in the second of the instruments of Mr. Lorieux mentioned above.

THE STADIMETER.

In Mr. Brunner's collection was exhibited an instrument called the stadimeter, invented by Messrs. Peaucellier and Wagner, of the imperial topographical corps of France. This is a horizontal rule bearing strongly-marked divisions, which are numbered from the centre in both directions, the whole being supported by a vertical rod in the manner of a signal mark on an engineer's levelling rod. The marks are in white on black, for the sake of greater distinctness, and the numbers are inverted that they may appear upright in an inverting telescope. This part of the

Fig. 120.



Brunner's Stadimeter.

apparatus is represented in Fig. 120. In the focus of the eye-piece are two fixed micrometric lines, and the determination of distance is made by observing how many divisions of the stadimeter are embraced between these lines.

The manner of observing is as follows: The stadimeter is fixed at the distant station, with its support truly vertical, and the plane of its arms at right angles to the line to be measured. The observer at the telescope turns the instrument in azimuth by means of a tangent screw, so as to make the two lines of the micrometer cut, if possible, two similarly numbered divisions. Thus if these lines fall exactly on the divisions 1, right and left, the distance is one decameter; if on the divisions 2, it will be two decameters; if on the divisions 3, three decameters, and so on.

But, as a general rule, the divisions will not fall exactly on the wires. In this case after observing the largest division which the lines of the micrometer will embrace, the division of that number on the right-hand arm x' is brought into exact coincidence with its wire, and by turning an index, k, in a dial marked j, the arm x is moved outward horizontally until coincidence is obtained with the corresponding division of that arm also. A horizontal index marked h shows how many subdivisions the arm is thus moved. Each space between the divisions is subdivided, as will be seen, into five parts. And as the value 1-1 is equivalent to a decameter, each of these spaces is equivalent to a meter. As the distance moved may not be an exact number of these subdivisions the fractions below a meter will be given by the dial j. The index of this dial makes an entire revolution in advancing the arm x one subdivision. The dial itself is divided into ten parts. Each of these parts corresponds to a decimeter. The centimeters may be estimated from observing the final position of the index k between the divisions of the dial.

The two arms are constructed in parts which fold back on each other, hinging half-way between the numbers eight and nine. For moderate distances, not exceeding eight decameters, the outer wings need not be unfolded. When they are employed, the distance measured may be increased to fourteen and a half decameters. There is also in the telescope a central line, dividing the space between the micrometric wires into two equal parts. For distances exceeding one hundred and forty-five meters this central line may be used with one of the lateral lines, in which case the divisions of the stadimeter indicate double decameters.

The telescope has another peculiarity, which is of great advantage in measurements in which the two stations are not on the same level. The indications which it gives are the true distances as projected on a horizontal plane. This result is accomplished by means of a construction called by its originator, Mr. Porro, *stenallatic.*

Since the number of divisions on the stadimeter intercepted by the fixed lines of the micrometer is the measure of the distance, this peculiarity of the construction must consist in maintaining the dimensions of the image at the same value, wherever the object may be situated in the same vertical. But inasmuch as the distance of the object from the observer increases as it is elevated in a vertical line above, or depressed in the same manner below the horizontal, in the ratio of the hypothenuse of a right-angled triangle to the base of the same triangle, or in that of the radius to the cosine of the angle of elevation or depression, the image in an ordinary telescope grows smaller under these changing conditions. The stenallatic contrivance is designed to counteract this effect. It does so by means of the following expedient.

In telescopes and in microscopes, when it is desired to exalt the magnifying power without increasing materially the length of the instrument, it is a plan which opticians frequently adopt to introduce within the tube a concave lens, called an amplifier. The effect of this upon the magnitude of the image varies with the position which it occupies between the objective and the ocular. As in the stenallatic telescope, the object to be gained is a virtual enlargement gradually increasing and always exactly compensating the diminution of size produced by the increasing distance of the object, it is easily seen that this effect may be secured, provided we can contrive a mechanism which shall move an amplifying glass in the interior of the telescope, in such a manner that its optical effect shall be just equal and opposite to that produced by varying the position of the observed object in the vertical passing through it.

In order to devise such a contrivance, it is necessary to know the relation which subsists between the image and the object observed, as to their linear dimensions. To ascertain this, we consider—

1. That when an image is formed by a single lens, the diameters of the image and object are to each other directly as their distances from the lens.

2. When an image is formed by the joint or consecutive action of two lenses, we may treat the case as if the first of these two lenses had produced its effect without the presence of the other; and then regard the image thus formed as the object of the second lens.

3. If a is the distance of an object from the center of a convex lens, b the distance of the image formed in the focus conjugate to a, and f the distance of the principal focus, or focus of parallel rays, the law will be found to hold, which is expressed in the equation

$$\frac{1}{f}=\frac{1}{a}+\frac{1}{b}. \quad \text{Whence, } b=\frac{af}{a-f}.$$

And if A be the space on the stadimeter, whose image is included between the lines of the micrometer, and B the actual distance between those lines themselves, then (according to [1] above,)

$$\frac{A}{B}=\frac{a}{b}=a\div\frac{af}{a-f}=\frac{a-f}{f}; \quad \text{And } B=\frac{Af}{(a-f)}=\frac{Af}{x}.$$

As f is a constant, we may conveniently put x for $a-f$; and this letter will then represent the distance of the stadimeter from the focal point of the object glass exterior to the glass.

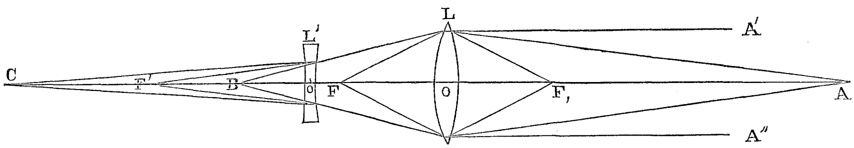


Fig. 121.

In this figure, L represents this object glass; A, the place of the stadimeter; B, the place where (in the absence of the other lens represented) the image of A would fall; and F and F′ the positions of the focal points of L, interior and exterior.

4. In proceeding to find the place and magnitude of the ultimate image formed by the joint action of the two lenses L and L′, the object, or radiant, in reference to L′ must be assumed to be at B. It is a necessary condition, in the case in hand, that B should be nearer to L′ than F′, its principal focus: otherwise the rays after being acted on by L′ will form no real image, while it is essential to the purpose in view that there should be a real image in the plane of the micrometer spider-lines. This being understood, we shall have the radiant, (negative in this case,) the principal focus, and the ultimate image, in the order which the figure shows, at B, F′ and C. Represent their distances from the centre of L′ by the letters b', f' and c'. We shall have then

$$\frac{1}{f'}=\frac{1}{b'}-\frac{1}{c'}. \quad \text{Whence } c'=\frac{b'f'}{f'-b'}.$$

And if C and B be taken as the measures of the images formed at the points marked by those letters respectively, we shall have,

$$\frac{C}{B}=\frac{c'}{b'}=\frac{b'f'}{f'-b'}\div b'=\frac{f'}{f'-b'}.$$

In this expression, if we put for B its value found above, (3) there will result,

$$\frac{Cx}{Af}=\frac{f'}{f'-b'}\,;\quad \text{whence } \frac{A}{C}=\frac{(f'-b')\,x}{ff'}.$$

Now if s is the space or distance between the lenses, b' is equal to $b-s$. And in (3) above, we have

$$b=\frac{af}{a-f}=\frac{af}{x}=\frac{(x+f)f}{x}=f+\frac{f^2}{x}.$$

So that $b'=b-s=f+\frac{f^2}{x}-s$, which, substituted in the expression foregoing, gives

$$\frac{A}{C}=\frac{(f'-f-\frac{f^2}{x}+s)x}{ff'}=\frac{(s+f'-f)x-f^2}{ff'}.$$

In the figure, s is OO′, f' is O′F′, and f is OF. Whence $s+f'-f$ is FF′ the distance between the principal foci of the two lenses. Put then this distance$=d$, and we shall have

$$\frac{A}{C}=\frac{dx-f^2}{ff'}.$$

Since f and f' are constant quantities, if the product, dx, can be made constant also, the ratio of A to C will be unaltered, or the image will remain of the same constant magnitude. We can vary this distance d, by moving the amplifying lens. What is necessary, is, that we shall move it so that d shall vary inversely as x. If, in this figure, BA be the horizontal distance of the object, then the distance BC or BC′, under the angle of elevation or depression, ABC, ABC′, will be expressed by

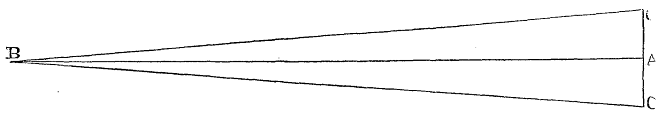


Fig. 122.

$$BC=\frac{BA}{\cos ABC}.\quad BC'=\frac{BA}{\cos ABC'}.$$

Hence the distance between the foci of the two lenses must be made to vary directly as the cosine of the angle of inclination to the horizon.

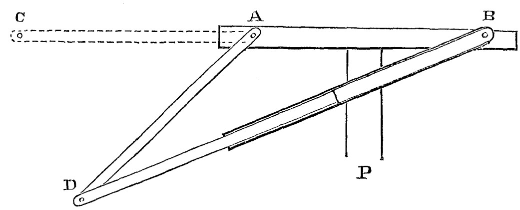


Fig. 123.

A mechanism producing a variation according to this law is illustrated in principle in Fig. 123. Let A B be two fixed points in a horizontal bar, supported by an upright P. Attached to these two points let there be two arms so pivoted as to turn freely. The arm pivoted at B is to be constructed hollow; and a rod sliding within it is to be pivoted to

the extremity D of the arm pivoted at A. In consequence of the connection thus established, neither of the two arms can turn without causing the other to turn; and with every change of position of the arms there will be a variation of the distance between the points B and D. This distance will reach its maximum when the arm takes the horizontal position AC. Suppose now the arm AD to be equal to the distance AB. The triangle ABD is isosceles, and the base BD has the value expressed in the equation,

$$BD = 2AB \cos ABD.$$

Now since AB is horizontal, the angle ABD is the angle of inclination of BD to the horizon; so that if the two lenses, in the case supposed, were fixed so that their focal points should be at the points B and D, the distance of these points from each other would vary according to the required law.

The manner of adapting a contrivance of this description to a telescope, so as to make the instrument fulfill the prescribed condition, is shown in Fig. 124. Here we have the triangle ABD of the previous figure repeated in the triangle ACD; and on the other side of the middle point C, of the horizontal bar AB, we have another similar triangle, BCE. AD, AC, BC, and BE, are all equal to each other. The tube DE, which is pivoted at C, has within it two sliding tubes, one of which carries the object-glass, and the other the eye-glass. These sliding tubes are moved by the arms AD, BE, which are connected with them at the points D and E, by pivots passing through slots in the outer tube. It is evident in this construction, as in the former, that

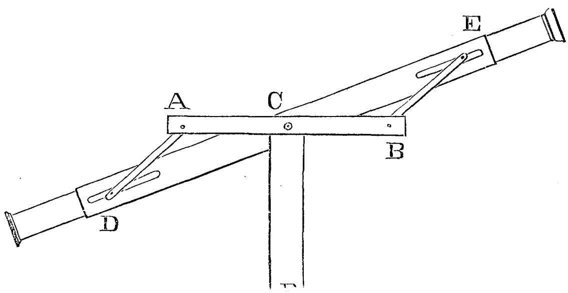


Fig. 124.

$$DE = 2AB \cos ACD.$$

Suppose, therefore, that the points DE are such that, when the telescope is horizontal, the distance between them is equal to the distance between the principal foci of the glasses, taken on either side of the glasses respectively, but both on the same side, it will be true of them in any other position that their distance will be such as to give always the true horizontal distance of the object observed.

The principle of the necessary mechanism being thus established, it becomes a mere matter of mechanical detail to perfect the application. It is unnecessary, therefore, to descend more minutely into the description of the instruments exhibited, in which it was exemplified. One observation, however, may be added. Inasmuch as it appears from the

examination of the theory of stenallatism above given, that the horizontal distance indicated by the instrument is measured from a point in front of the object-glass, and as far in front of it as the distance of its principal focus, it is evident that when the telescope is inclined, this point describing a circular arc will occasion a slight error in the indication. In general, the error will be too small to require correction, except for purposes which demand severe exactness. The corrections may be easily tabulated and applied when necessary. Mr. Porro has not been willing, however, to permit even this imperfection to impair the theoretic perfection of his instrument. He has introduced an additional mechanical contrivance, by means of which the whole body of the telescope is advanced or retracted in the direction of its length by the exact amount necessary to preserve the constancy of position of the initial point of horizontal measurement, thus making the instrument independent of tabular corrections. In this improved form, he gives to the instrument the name of the anallatic telescope.

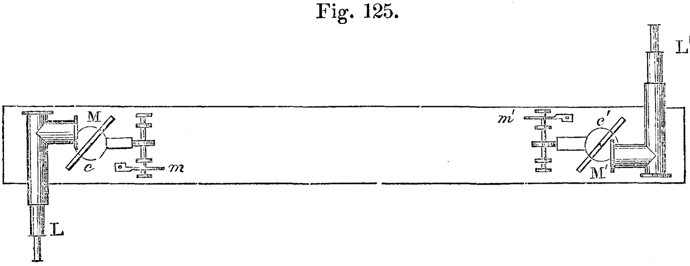
Several forms of double-image instruments have been constructed and to some extent heretofore employed, which were not present in the Exposition, or if present were not observed. In one of these the object-glass is divided through the middle, like that of a heliometer, showing a single image when the two halves of the lens are in their original position so as to form one whole, and two when the two halves are displaced by a movement in the direction of the line of division. The amount of movement necessary to bring the two images of a known object into contact by their edges, serves to indicate the distance; which is then inscribed on the scale in a number of which the measured dimension of the object observed is the unit. A simple and exceedingly portable instrument analogous to this is one in which the eye-glass is divided. The telescope is on the Galilean plan, and the movement of the divided eye-piece is effected by means of a lever which can be managed by the thumb of the hand which holds the instrument. This is designed to be used on horseback, the whole being small enough to be carried in the side pocket of the coat. For cavalry officers it is very convenient, giving approximately the distance of a man or body of men, by assuming six feet as the average height of a soldier with his chapeau. The scale is so inscribed that its indications may be read while the instrument is held in a manner convenient for observation.

TELEMETRIC DOUBLE TELESCOPES.

For the determination of distances by means of observations upon objects whose dimensions are unknown, it is necessary in general to obtain a parallax, or angle subtended at the distant station by a base at the point of observation. Instruments have been constructed with two telescopes fixed at the extremities of a bar or rod of determinate length, one of them being movable in azimuth over a divided circle, while the other is fixed. When the index of the movable telescope is at the zero of

the graduation, the two axes ought to be parallel. An adjustment to this condition is effected by observing a horizontal object, placed at a convenient distance for the purpose, equal in length to the bar to which

Fig. 125.



Balbreck's Telemetric Double Telescope.

the telescopes are attached. When one extremity of this object is brought exactly to the central line of the micrometer of the telescope at the corresponding end of the bar, the other must be turned in azimuth until a similar coincidence is obtained with the other end. The axes of the telescopes are then parallel, and the circle or the index must be moved, without disturbing the telescope above it, until the index marks truly zero. If then both telescopes are directed at the same distant point, the parallax may be directly read.

Mr. Balbreck, of Paris, exhibited an instrument of simpler construction, founded upon the same principle, which is represented in plan in the figure. A square box contains two mirrors M and M′, turning on vertical pivots at their middle points. Their movements are commanded by tangent screws, represented at *m* and *m′*, each carrying a divided circle with an index by which the amount of movement may be read. These mirrors are in part silvered and in part transparent. They are represented in Figs. 126 and 127. The parts marked *r* are silvered on one side, and those more darkly shaded on the other. The parts unshaded are transparent. The box is mounted on a tripod by means of a central pivot, around which it may revolve horizontally. This pivot is fixed to the tripod by a ball and socket joint, which allows the plane of revolution, if necessary, to be inclined. Two telescopes are also attached to the apparatus, each making a right angle in the interior of the box; a rectangular glass prism being placed in the angle to change the direction of the rays by total reflection. The eye-pieces of these telescopes are presented at right angles to the axis of the box in opposite directions. The distance between the centers of the mirrors is one meter. In the sides of the box opposite the mirrors are openings to admit the light from the object to be observed.

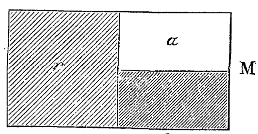


Fig. 126.

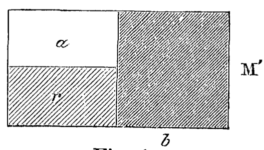
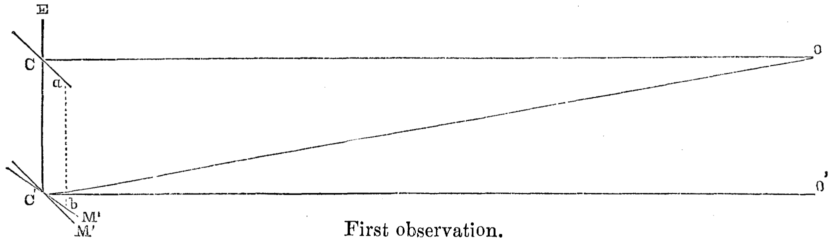


Fig. 127.

The use of the instrument may be thus explained. Let us suppose, at first, that the two mirrors are at an angle of forty-five degrees to the

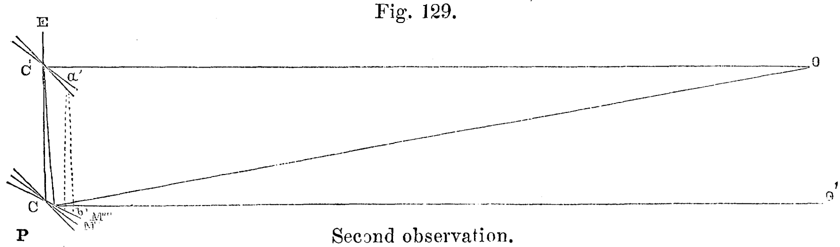
axis of the box; and that the telescopes are parallel to each other, their axes being at right angles to that of the box. By turning the whole nstrument about its pivot, let the image of a distant point as seen by reflection in the mirror M be brought to coincidence with the central line of the micrometer in L. Then, through the transparent part of M, the same point will be seen by reflection from the mirror M′, but not on the central line. The tangent screw *m′* must therefore be used to bring it to the center. Suppose O to be the place of the object. Then the rays O M and O M′ will form an angle with each other equal very nearly to the parallax sought—that is, to the angle at O subtended by the base, one meter, which is the distance between the centers of M and M′. The mirror M′ will, according to the well-known law of reflection, have been turned through an angle equal to half the parallax. Let now the box be revolved one hundred and eighty degrees on its pivot. The telescope L′ will now come into the position for observation, and the mirror M′ will be that which will reflect the right-hand image to the eye. This is the mirror which has been turned by the micrometer screw. When the image as reflected by it is brought to the central line by turning the box as before, the other image, now reflected from M, will be twice as far from the center as in the former case. By turning the tangent screw *m*, the mirror M will first come into parallelism with M′, when the appearance of things will be the same as that first presented, and afterwards passing beyond the position of parallelism, will bring the second image again to coincide with the first. The dial of *m* will then show twice as large an angular movement as that of *m′*; and this reading will be very nearly the true parallax. That it needs a correction to make it quite true will appear from examining the accompanying diagrams, Figs. 128 and 129.

Fig. 128.



First observation.

Fig. 129.



Second observation.

Disregarding the angular form of the telescope, suppose the observer's eye to be at E, and that the object O is seen in the line C E. Another

object O′, one meter distant from O, will be seen reflected from M′ in the same direction, while another image of O will be observed in that mirror out of the center. When coincidence is established by turning M′, the rays from O reflected from the second mirror will follow the line C′ C E. The mirror M′ will then have a new position, which may be represented by M″.

Revolving the instrument, the left-hand image will be seen in M″, the reflected ray taking the direction C′ E, the axis of the box having now a position deviating from that which it had originally, by half the angle O C O′. M will have to be brought to the position M‴ in order to establish parallelism anew between the mirrors, when the object O′ will be seen in the direction P C′ E; and afterward to the position M⁗, to bring both images of O together. The angle M C M⁗ is now very nearly the parallax, and for any but very exact determinations may be taken as the actual parallax. There is a slight error in the measurement, which arises from the fact that the line C′ P is not exactly equal to the line C′ C. An exact correction is not simply effected; but if the measured parallaxes corresponding to a series of known distances be tabulated, very accurate results may be reached. The instrument can be used very rapidly, and by repeating the observations in successive revolutions, the parallax may be doubled, trebled, &c., at pleasure.

ELECTRIC TELEMETERS.

Among the objects exhibited in the Austrian section by the war department of that empire there was an ingenious apparatus for meas-using the distances and determining the positions of objects in motion, by means of observations conducted simultaneously at two stations, distant and not necessarily in view from each other. Electricity is here called in to assist in the determination. The inventor is Captain Kocziczka, of the imperial-royal corps of engineers. The following description is transcribed from a report to a scientific journal:

"This apparatus requires two points of observation placed at a certain measured distance from each other, and connected by a telegraph wire. At each of these stations a telescope is used for observing the object in view, and below the telescope a small table is placed in one of the stations, representing the map of the space in front of the observer. At one fixed point upon the table exactly below the axis of the telescope there is a long thin needle balanced upon a point, and connected to the telescope, so as to follow all movements of the latter and to be always parallel to its line of sight. Besides this, a second needle, which turns round a point which represents the second point of observation upon the small map, is placed upon the table, and this second needle is connected with the telescope of the other station by an electric arrangement. The movement of the distant telescope is made to cause this needle to turn to an equal angle with itself, in a somewhat similar manner to the magnetic needles of the electric telegraph. The distance between the cen-

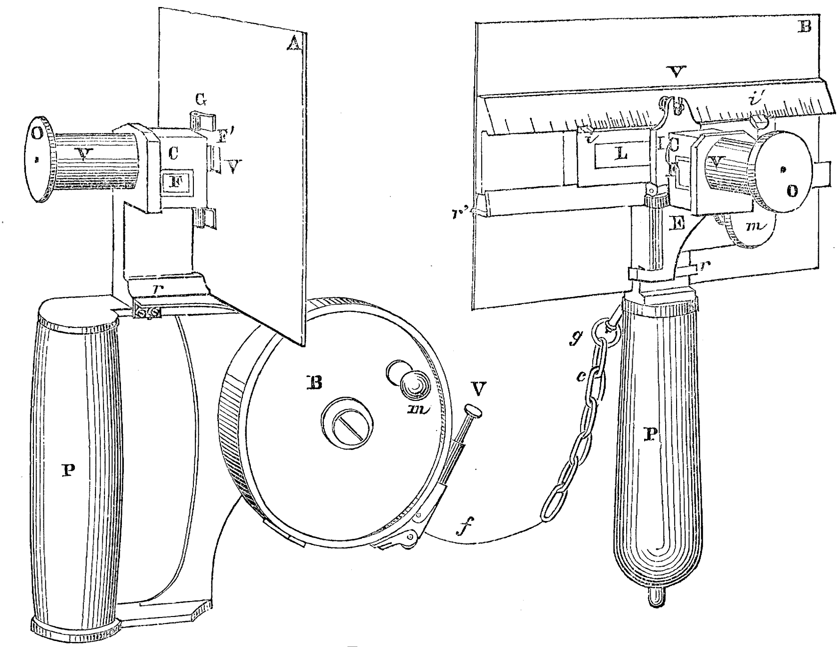
ters of the two needles on the paper being made to scale, so as to represent the measured distance of the two places of observation, it follows that the position of the two needles will indicate the two lines of sight of the two telescopes both fixed upon the same distant object, and the point where the two needles cross each other (one of the needles being slightly below the other) will correspond to the exact position of the distant object. If the latter is in motion, and the two observers follow its movements so as to keep it constantly in sight, the two needles will constantly change their position, and their point of intersection will make the same movements upon the map, on a small scale, as the distant object makes in reality; the movements of the object and those of the point of intersection of the two needles being simultaneous. For purposes of warfare there are several applications of this instrument which will readily suggest themselves; but similar instruments may be used with advantage for purposes of general surveys of land, and for similar operations where they are not unlikely to effect some considerable saving of time, if properly employed."

Another invention analogous to this was exhibited in the same collection, originated by the Archduke Leopold, of which the object is to determine the moment when a hostile vessel passes over the position of a submerged torpedo, and also simultaneously to explode the mine. In this case two observers stationed at a distance from each other are necessary; but the distance need not be measured. Supposing that a series of torpedoes is submerged in a straight line, one of the stations is in the prolongation of that line, and the business of the observer is to watch the passage of the enemy's vessels across it. The other station commands a cross view of the same line; and at this station the exact directions of the several submerged magazines are known. The telescope is of the altitude and azimuth construction, and an insulated metallic arm which turns with the azimuth circle touches successively a series of insulated conductors, which communicate severally with the magazines toward which the telescope is at the moment directed. This contact closes a circuit which passes through both stations, and is broken at both, except when closed from time to time at the second in the movement of the telescope as just described, and intentionally at the first by the observer himself. It is the business of this first observer to touch the electric key whenever a vessel crosses the line. The second observer having his telescope directed at the same vessel, will necessarily, though unconsciously, close the circuit, if the vessel happens to pass over a magazine. The touching of the key at the first station thus completes the circuit throughout, and the mine is exploded. But if the vessel happens to cross the line at a safe distance from any of these lurking dangers, there will be no contact at the second station, and the touching of the key will be without effect.

PRISM TELEMETER.

The prism telemeter has undergone a recent improvement, which renders it much more commodious in use than it was in its original form. The instrument consists of two prisms of observation, connected by a measuring tape or chain which serves to determine the length of the base on which the parallax is to be ascertained. These prisms are suitably mounted and provided with handles for the convenience of the observers. They are represented in their external appearance in Fig. 130 annexed, and in section in Fig. 131. From the section it appears that the

Fig. 130.



Prism Telemeter.

prisms are four-sided, the reflecting sides, which are silvered, being at an angle of forty-five degrees to each other, so that a ray which enters at *a*, after two interior reflections emerges at *d*, at right angles to its original direction. The prisms are inclosed in the boxes marked C, (Fig. 130,) of which they occupy but half the height, so that the observer looking through the tubes marked V, can see an object directly before him through an aperture V on the screen A, while he sees, at the same time, another object situated to the right or left, by reflection in the prism, through the aperture F.

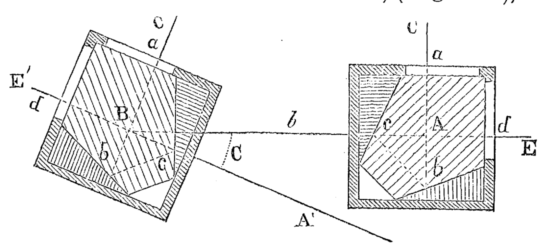


Fig. 131.

The two objects thus seen are apparently coincident in direction; but really the rays coming from them to the prisms, cross in the interior of the prism (as seen at A, Fig. 131) at right angles to each other. The observing apparatus is hinged to the screen at G, for convenience in packing. B, Fig. 130, is a box containing the measuring tape.

This instrument was originally constructed in such a manner that in using it both observers stood facing the distant object. The observer on the left hand kept his position, while the observer on the right moved, at the extremity of the stretched measuring tape between them, until his prism was seen by the first observer, in coincidence with the distant object. The second observer then looking toward the distant object C, Fig. 132, would see coincident with it, not A, but some object or point behind A, as A′. If the distance A A′ (supposing A′ to be in the line C A continued) could be accurately ascertained, the distance C A would become known, since, in the right-angled triangle A′BC, AB is the perpendicular to the hypothenuse drawn from the right angle, and

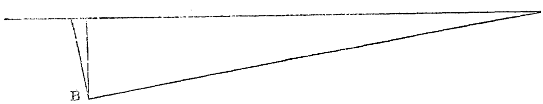


Fig. 132.

$$AB^2 = AA' \times AC; \text{ or } AC = \frac{AB^2}{AA'}.$$

In order to measure this distance, AA′, the prism of the left hand observer was provided with a measuring arm or rod firmly attached to its handle, and extending, when the instrument was held before the eye, backward over the observer's right shoulder. This arm carried, also, a sliding sight vane, which was to be the mark of the observer B. The position of this mark, first assumed conjecturally, was altered by the observer A, as required by the other observer, until the desired coincidence was secured. The reading on the arm then gave the distance AA′ sought.

As it was customary, in practice, to employ a measuring tape of constant length, say twenty meters, the actual distances, AC, corresponding to the various readings with that length of base, were themselves inscribed on the arm, so that no calculation was required, except for interpolation in case the mark happened to fall between two graduations.

In the present construction, the two observers look directly at each other, and both see the distant object by reflection, the rays entering the instrument from the right for one, and from the left for the other. In Fig. 131, if we suppose the distant object to be in the direction CA for the right-hand prism, then, if at the position B there is a sensible parallax, the object will appear in a somewhat different direction, as CB. And the observer must look at right angles to this direction, in order to see it, that is to say, in the direction E′B. By extending this line it will encounter some object, as A′, which is to the right of A. The

recent improvement, which is due to Captain Goulier, of the French engineer corps, consists in introducing between the prism B and the eye E′ an optical compensator for the deviation, ABA′, which causes the emergent ray proceeding from A′ to assume a direction at the eye, parallel to or coincident with AB. This compensator consists of a zone cut from the middle of a plano-convex lens of large diameter, and a similar zone cut from a plano-concave lens of the same size and radius of curvature. When two such zones are superposed concentrically upon one another, the spherical sides being in contact, they form unitedly a plate of plane glass with parallel surfaces, incapable of changing the direction of rays of light transmitted through them. But if one of them is moved in the direction of its length, while the other remains stationary, then any ray which passes through the center of either will be bent by the other.

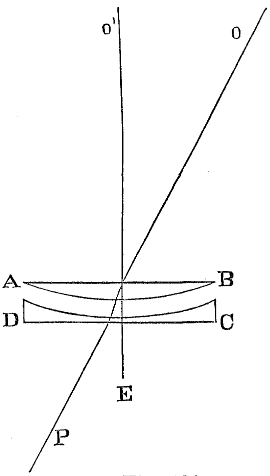


Fig. 133.

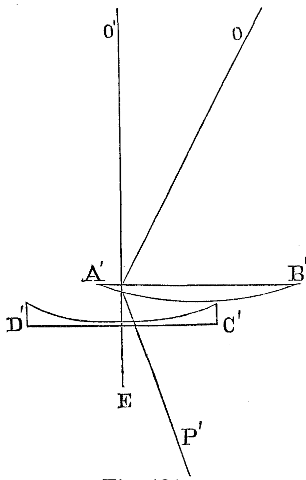


Fig. 134.

In Fig. 133 we have first the concentric position of the plates, and the object O is seen in its true position by the eye at E. In Fig 134 we have the convex lens displaced toward the right in A′ B′; and the ray from O′ will take the direction of P′ after passing the system, and will escape the eye at E. But another ray coming obliquely from a different object, O, will be bent in such a manner as to fall into the direction O′E; and if OA′O′ be equal to the angle of parallax in any observation, say ABA′ in Fig. 131, the system A′B′C′D′, interposed between the eye and the prism B, will make the direction of the distant object coincide with BA, or interposed between the eye and the space above the prism through which A′ is seen in the same figure, it would make A appear in the direction E′B; only that, in this case, it would be necessary to displace the convex band in the direction opposite to that shown in Fig. 134, or toward the left.

This system of lenticular zones is introduced into the apparatus on the right, Fig. 130, at the point marked L. The concave band is fixed, and the eye always looks through its optical center. The convex band is movable, and is displaced by the observer by means of a milled head. The deviations of the ray produced by displacement are sensibly proportional to the displacements themselves, or to the distances of which

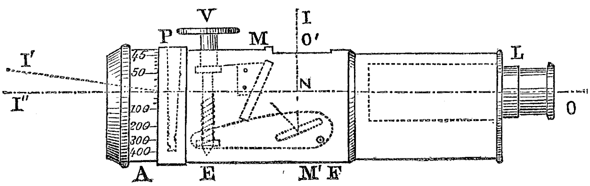
they are the parallaxes. These distances may, therefore, be marked on the scale which indicates the amount of displacement, when the length of the base line is fixed.

Observations with this apparatus may be very rapidly made, and their facility is such that it is usual to take as many as ten successively, and to adopt the mean result. With a base of twenty meters, the mean error for distances up to one kilometer is one-half of one per cent.; for distances as great as two kilometers or upward, two per cent., increasing as the square of the distance. By using a base twice as large—forty meters instead of twenty—the errors are reduced to one-half the foregoing. These determinations are made without a telescope. While a telescope may increase the accuracy of the results, it sensibly diminishes the facility of observation.

TELEMETRICAL SINGLE TELESCOPES.

A telemetrical telescope, invented by Captain Gautier, of the imperial artillery, was exposed by the constructor, Mr. Gravet Tavernier, which, for its extreme portability and its remarkable accuracy, might be regarded as the most ingenious instrument of its kind in the Exposition. It consists, as shown in the figure, of a tube about five inches in length, having a short telescope with concave eye-piece, low magnifying power, and a narrow opening for vision at the end L, and two mirrors, M and M′, making an angle of 45° with each other, which occupy about half the breadth of the anterior part of the tube, leaving room for direct observation by means of rays coming in the direction I″ O. In front still of the mirrors is a glass prism P, having an angle of about six degrees. This prism is attached to a ring which turns on the end of the tube, and is graduated with numbers increasing from 0 to ∞. In the side of the tube, which, in the figure, is represented as seen from above, is an opening, O′, through which rays coming from a distant object in the direction I O′ may reach the eye at O, after undergoing two reflections from the mirrors M and M′. The mirror M′ is fixed to a lever EF, which turns on the pivot F, and is commanded by the screw E and milled head V and allows the angle made by the mirrors to be slightly varied. An index is attached to the lever EF on the under side, which indicates the exact angle at any time made by the mirrors. This angle may be read through an opening in the tube beneath the lever, which does not appear in the figure. The prism causes the rays entering the instrument from the objects toward which it is directed to deviate

Fig. 135.



Gautier's Telemetrical Telescope.

by an amount, I′KI″, equal to half the angle of the prism, or three degrees. By turning the ring A, which carries the prism, the ray I′K will describe around I″K as an axis, a conical surface, so that its lateral deviation will vary between the extreme limits of three degrees right and left, passing through zero at the intermediate points of the revolution.

In using the instrument it is first adjusted by turning the ring A until the mark ∞ is under the index. The index of the lever EF must also be brought to its zero. In this condition the edge of the prism is vertical, and objects seen through the prism are displaced toward the right. The mirrors are also truly at 45° from each other, and the angle at N is a right angle.

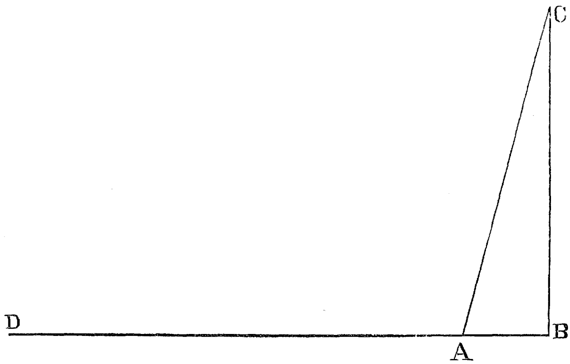


Fig. 136.

Let the observer be stationed at A, and let C be the object of which it is required to ascertain the distance. Holding the instrument, which for convenience is attached by means of an India-rubber band to the end of the case in which it is ordinarily carried in the pocket, before his eye, the case serving as a handle, the observer brings the object C into view; and then among the objects in the direction D selects a suitable one for his purpose, taking it by preference a little to the left of the image of C seen by reflection. The reason of this is that by so doing the angle DAC will be made a little over a right angle, so that when a second observation is taken from a point further from D, as B, the triangle ABC will be very nearly or quite right-angled. By means of the milled head V he then brings the selected object D into coincidence with the image of C upon a line traced on the center of the mirror M. This done, he moves in the direction DA to a convenient point, B, more remote from D, and observes once more. The natural object will now appear to the right of the reflected image, because the angle DBC is less than DAC by the amount of the parallax. Coincidence is established anew by turning the ring A, which displaces the object D toward the left. When this is accomplished the graduation under the index of A will give a factor, which multiplied into the distance AB will give the distance AC.

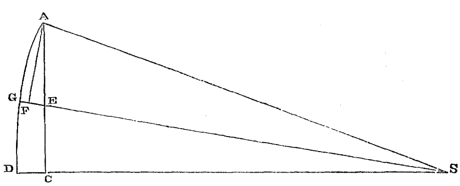


Fig. 137.

The graduation is the inverse of the sine of the parallax, and as, assuming in the last figure that B is a right angle—

$$AC = \frac{AB}{\sin \pi}; \text{ hence } AB \times \text{the inverse of } \sin \pi = AC;$$

π being taken to represent the parallax.

To determine the divisions of the graduation, therefore, let ASC, Fig. 137, be a section through the summit S of the cone described by the revolving ray, and in this plane, with the radius SA, describe the arc AD, which will be equal to three degrees. Suppose the revolving ray to have been carried by the movement of the ring from A through an angle φ in the base of the cone. A plane through the ray perpendicular to ACS will cut this plane in a straight line, as SE, and the movement in parallax will be the angle ESA. Drop the perpendicular AF upon SE produced, and call it p. Put $AE = q$, $AS = R$, and $AC = r$.

$$\text{Then } p = R \sin \pi. \quad \text{And } p = q \cos (3^\circ - \pi).$$

$$\text{Hence } R \sin \pi = q \cos (3^\circ - \pi). \quad \text{And } q = R \frac{\sin \pi}{\cos (3^\circ - \pi)}.$$

$$\text{But } q = r \text{ v. s. } \varphi. \quad \therefore r \text{ v. s. } \varphi = R \frac{\sin \pi}{\cos (3^\circ - \pi)}; \text{ or } \frac{r}{R} \text{ v. s. } \varphi = \frac{\sin \pi}{\cos (3^\circ - \pi)}.$$

$$\text{But } \frac{r}{R} = \sin ASC = \sin 3^\circ. \quad \text{Hence v. s. } \varphi = \frac{\sin \pi}{\sin 3^\circ \cos (3^\circ - \pi)}.$$

$$\text{And finally, } \cos \varphi = 1 - \frac{\sin \pi}{\sin 3^\circ \cos (3^\circ - \pi)}. \text{(I.)}$$

Also considering that $\cos (3^\circ - \pi) = \cos 3^\circ \cos \pi + \sin 3^\circ \sin \pi$, we deduce

$$\frac{\sin \pi}{\cos \pi} = \tan \pi = \frac{\sin 3^\circ \cos 3^\circ \text{ v. s. } \varphi}{1 - \sin^2 3^\circ \text{ v. s. } \varphi} = \frac{0.05227 \text{ v. s. } \varphi}{1 - 0.00274 \text{ v. s. } \varphi}. \quad \text{(II.)}$$

If φ is given, π may be found from (II.) If π is given, φ may be found from (I.)

By assuming a series of parallaxes, beginning with zero and ascending by small differences, the divisions of the ring A may be determined; and the number to be inscribed at each division will be equal to $\frac{1}{\sin \pi}$.

Thus for $\pi = 0^\circ$, $\cos \varphi = 1$ and $\varphi = 0^\circ$. For $\pi = 3^\circ$, $\cos \varphi = 0^\circ$, and $\varphi = 90^\circ$ For $\pi = 1\frac{1}{2}^\circ$, $\cos \varphi = 1 - \frac{1}{2} = \frac{1}{2}$ very nearly; and $\varphi = 60^\circ$. The multiplier for $\varphi = 0^\circ$ is $\frac{1}{\sin \pi} = \frac{1}{0} = \infty$; for $\pi = 3^\circ$ it is 19.1, nearly, and for $\pi = 1^\circ$ it is 57.3, nearly; but the parallaxes are chosen in such a manner as to give round numbers in the graduation.

Another mode of making the second observation is the following: The instrument is accompanied by a staff graduated to meters and fractions, and having a tripod stand to support it. The staff also carries sight-vanes. Before the observer leaves station A he turns the ring to any graduation which he thinks convenient, and leaving the staff at A, retreats toward B, until the coincidence of images, which has been destroyed for A by turning the ring, is accurately re-established. Suppose

that he had turned to the mark 100; then he has to measure the distance AB, and to multiply it by 100. The distance need not be measured on the ground, as the instrument, with the assistance of the staff, furnishes the means of measuring it optically. The ring is turned back to the mark ∞, the sight opening is placed parallel to the face of the screw-head V, and the telescope is turned with the screw-head uppermost. The staff can then be seen by direct vision, and also as displaced by refraction through the prism, the prism not occupying the whole breadth of the tube. In the position of the instrument supposed, the two images may be so superposed that one of them is the prolongation of the other. One of the sight-vanes is placed at the top of the staff, and the other is moved to such a point that, as seen by refraction, it coincides with the first seen directly. The angular displacement is three degrees, and is constant for all distances. The staff bears a graduation which tells directly the distance AB at which the observation is made.

The accuracy of measurements made by this instrument is extraordinary. With a base of twenty meters the error for distances below a kilometer is almost imperceptible. Distances of from three to six kilometers, and even more, have been measured by it, with bases of from twenty to fifty meters, with a maximum error not exceeding one-fourth of one per cent.

II.—INSTRUMENTS FOR ANGULAR MEASUREMENT.

THEODOLITES.

Though the theodolites exhibited were very numerous, and were many of them admirable in workmanship, there was hardly sufficient of novelty in the construction of this class of instruments to detain the reporter long. Many of the continental theodolites are constructed with a view to the measurement of vertical angles from the zenith downward. This object can only be secured by placing the telescope at the extremity of the horizontal axis, an arrangement which, in measuring horizontal angles, involves the necessity of a correction for the center, which is laborious and troublesome. It permits, however, observations for collimation to be made from the surface of mercury, as in the case of the astronomical transit instrument. To facilitate this observation, Mr. M. Balbreck, of Paris, whose instruments were among the most beautiful of those exhibited, introduces into the ocular, between the two lenses, a plane glass mirror with parallel surfaces, which admits of being placed at the angle of 45° to the axis, so as to throw the light received through an aperture in the tube from a lateral source, directly away from the observer and upon the spider lines in the focus. The lines are thus brilliantly illuminated, and the eye is not dazzled by the illumination. This mirror admits of being displaced to the side of the tube in ordinary observation.

Secretan, Brunner, Rigaud and others, in the French section, Pistor and Martens, of Berlin, and Breithaupt, of Hesse-Cassel, all exhibited

theodolites of admirable construction. Those of Breithaupt presented the peculiarity that the graduation of the horizontal circle is protected by a glass plate, which also protects the vernier, and which permits the divisions to be read while excluding dust and moisture. This construction is especially advantageous in theodolites for miners, of which this exhibitor presented several patterns. Another peculiarity of Breithaupt's theodolites consists in the use of a differential tangent-screw for slow movement. This screw is not a Hunter's screw, in which, as is known, one screw works within another of a slightly differing thread. On the other hand, in the present case, two threads are cut upon the different ends of the same rod. One of these corresponds to the thread of the tangent-screw in the common construction, and is that by which the slow movement is directly produced. The other runs in a fixed nut attached to the clamp-plate, answering to the stud by which the common tangent-screw is held, and which serves as its fulcrum. These two threads being unequal, the motion imparted to the instrument is equal to their difference.

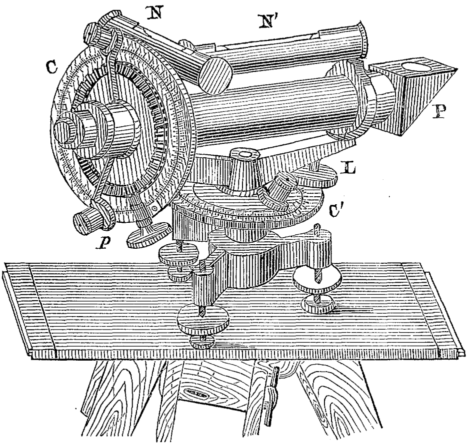
To the statement made above as to the absence of originality in the forms of the theodolites exhibited, an exception must be made in favor of the "traveling theodolite," invented by Mr. Dabbadie, the African explorer, which was shown by Secretan, and also by Eichens, in the French section, and by the Genevese Society in the Swiss. The object aimed at in the design of this instrument is to reduce the number of movable parts as much as possible, to dispense with screws wherever it could be done, and to make the whole instrument in the highest practicable degree compact and portable. The instrument as exhibited by Eichens has a telescope only twenty centimeters (eight inches) long, with an objective of one hundred and eighty-five millimeters (seven and one-half inches, nearly,) focal length, and a clear aperture of twenty-five millimeters, (one inch.) For the sake of commanding a large field of view, the magnifying power is carried only to eight times. The chief peculiarity of this instrument consists in the fact that the telescope has no motion in altitude, but is firmly supported in a horizontal position, with only a rotary motion around its axis of figure. The expedient by means of which vertical angles are measured with it is the following:

DABBADIE'S THEODOLITE.

Referring to the figure annexed, it will be seen that to the telescope tube is attached, immediately in front of the object glass, a large isosceles rectangular prism, having one of its side faces perpendicular to the axis of the instrument. The observer therefore places the instrument so that the telescope axis is at right angles to the vertical plane in which the object is situated of which the altitude is to be measured; and by turning the telescope in its supports the image of the object is seen by reflection in the prism. At the extremity next the eye, the telescope carries a vertical circle of ten centimeters (four inches) radius, divided

centesimally, and this is read by a vernier to one one-hundredth part of a degree. The horizontal points of the limb are not determinable by direct observation; but the zenith and nadir points are found with facility. For the nadir point resort is had, as usual, to reflection from the surface of mercury. For the zenith, a trough filled with water, and having as a bottom a plate of glass with parallel surfaces, is placed over the object end of the telescope. The upper surface of the water serves as a reflector. The zenith and nadir points being found, their circle readings, if correct, will differ by a semi-circumference. And it is easy at any time to verify their accuracy by observing the zenith distance of any object, and also that of its image seen by reflection in mercury, and adding the two. The sum should be a semi-circumference. The horizontal circle is of the same diameter as the vertical. The movements, both horizontal and vertical, are effected without tangent-screws, the rack and pinion only being used. Two cross-levels serve for the adjustment of the plane of horizontal movement. Mr. Eichens has also added a small compass to the instrument exposed by him. Nothing could be in appearance more convenient than this instrument for the use of the scientific traveler who desires to make observations upon the heights of mountains, the breadths of streams, or other matters of geographical or geodetical interest.

Fig. 138.



Dabbadie's Theodolite.

LEVELING INSTRUMENTS.

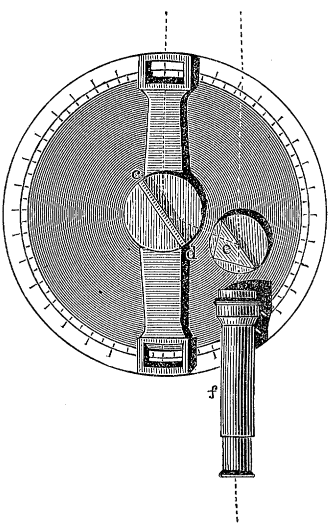
Leveling instruments of excellent construction were exhibited by Mr. Gravet Tavernier of Paris, and by Mr. N. A. Pierson, in which the levels admit of reversal without being detached; a very useful provision against accidents. In the Portuguese section there appeared also an instrument of this class, in which two telescopes parallel to each other, but looking in opposite directions, are so disposed as to turn about a horizontal axis parallel to both, by which arrangement either may be brought uppermost, and the backsights and foresights may be made without reversal. This construction is favorable to expedition, but whether it is equally so to accuracy remains to be proved. A peculiarity was noticed also in the leveling instruments of Breithaupt of Cassel, in which the supports of the telescope are hardened steel knife edges, resting on plates also of hardened steel.

REFLECTING INSTRUMENTS.

Among the reflecting instruments exhibited, the most noticeable were the circles of Messrs. Pistor and Martens, of Berlin, which by the arrangement of the fixed and movable mirrors very considerably increase the extent of angle commanded by the instrument. This arrangement is illustrated in the accompanying figure, in which *c d* is the index glass, *e* the horizon glass, and *f* the telescope. The horizon glass is not a silvered mirror, as in the common sextant, but an isosceles rectangular prism of which the diagonal face serves as the mirror by total internal reflection. In order that objects beyond the horizon glass may be seen by direct vision, the height of the prism perpendicular to the plane of the instrument is only half that of the index glass, and is such as to intercept only one-half the light coming from the object directly observed to the objective of the telescope. It is a little remarkable that the common sextant should have continued to be so long constructed with a horizon glass half silvered and half unsilvered, when the unsilvered portion is not only useless, but is a positive disadvantage.

Sextants are also constructed by Messrs. Pistor & Martens on the same principle; and with these the measurement of angles is carried up to 180 degrees. This cannot be done by holding the instrument in the same position throughout the whole range. It will be obvious, by referring to the figure of the circle here given, that after reaching a certain magnitude of angle, which depends upon the relative positions of *c d* and *e*, the rays from the object seen by reflection will begin to be cut off by the prism *e*. When this is the case, the sextant is turned with the limb uppermost, and the higher angles are read upon a different part of the limb. In the circle this expedient cannot be employed except by abandoning one of the verniers. If, for instance, in the figure, the upper index arm should be removed, the lower arm could traverse nearly the entire limb. As the sextants are constructed, all angles up to 140 degrees are measured with the instrument in the usual position. For angles between 140 degrees and 180 degrees the instrument is inverted, and the graduation begins at a new point about 60 degrees farther along the limb, reading in a direction opposite to the first. Where the angle approaches 180 degrees, the head of the observer begins to interfere. This case is provided for by adding a diagonal eye-piece to the telescope, which permits the observer to put himself out of the plane of observation.

Fig. 139.



Pistor & Martens's Circle.

LAURENT'S SEXTANT FOR STELLAR OBSERVATIONS.

Another modification of the sextant deserving of attention was exhibited by Captain Albert Laurent, formerly of the French naval service, and at present commander of the transatlantic steamer Imperatrice Eugénie. Captain Laurent observes that navigators lose, for the most part, the benefit of observations of stellar altitudes, in consequence of the difficulty of making the contacts of the image of the star with the horizon. His remedy for this difficulty is to elongate the image of the star in a direction perpendicular to the plane of the observation, whereby the object is made more conspicuous, and the facility of observation is greatly increased. The elongation of image here spoken of is produced by placing a cylindrical lens with its axis of figure parallel to the plane of the instrument, and its optical axis also parallel to the same plane and coincident with the direction of the rays proceeding from the star. The focal length to be given to the cylindrical lens depends upon the degree of elongation which it is desired to give to the star, on the focal lengths of the glasses of the telescope, and on the distance between the lens and the objective of the telescope. The inventor finds that an apparent angular elongation of the star equal at the eye to five degrees is about the most satisfactory; but as the observer sees only one-half of the total elongation, the lens ought to be capable of producing a lengthening effect equal to ten degrees.

As there is a practical advantage in making the distance between the lens and the objective of the telescope as great as possible, Captain Laurent has placed his telescope and his horizon-glass as near the graduated limb, and as far from the center of the instrument, as convenience in use will allow. For the sake of increasing the light, he has greatly enlarged the diameter of the telescope objective. This, in the instrument exhibited, must have been not less than four or five centimeters—between one and two inches, and nearer the latter. The unsilvered part of the horizon-glass is also suppressed, an improvement the value of which has been alluded to above.

It is asserted by Captain Laurent that the observations of the altitudes of stars made with the same instrument, with and without the elongating lenses successively, show an advantage as to accuracy of results in favor of his improvement in the ratio of five to one. He adds, "Besides this, the new method permits the observer to note those altitudes on which he can count with certainty; while formerly there remained in the observer's mind a doubt and uncertainty which took away all confidence. It could not be otherwise, since frequently there presented itself a difference between two successive altitudes of fifteen to twenty minutes, without there being any ground for preferring one of these observations rather than the other."

This new form of sextant was devised with especial reference to observations for latitude; but the inventor believes it also quite as well adapted

to determinations of longitudes, whether by observing the altitudes of the planets, or of bright stars, or by measuring lunar distances. Experience can only decide on the justice of this claim. In the mean time he informs us that the instrument has been recently introduced on board of several of the transatlantic steam-packets, with results which have much surpassed his expectations. "It has always been possible," he says, "to determine the latitude [with this instrument] with rigorous precision, however sombre might be the horizon, whether by the meridian altitudes of stars or by that of the pole star. The application to the determination of longitudes by stellar altitudes has furnished results remarkable for their exactness. It has been possible, by the aid of nocturnal observations, to trace upon the chart the vessel's route, not only from hour to hour but from minute to minute, and consequently to make land or to traverse the most dangerous waters by night, with an extreme security." This is perhaps saying too much; but at any rate there can be no doubt that the instrument is well worth the attention of navigators.

DAVIDSON'S SPIRIT-LEVEL SEXTANT.

Still another improvement of the sextant was exhibited in the department of the United States by Mr. George Davidson, of the United States Coast Survey. It may be said to be, as to its object, the converse of that of Captain Laurent, just described, inasmuch as the aim of that ingenious inventor is to make observations on the horizon as useful as possible, while Mr. Davidson proposes to be rid of them altogether. Moreover, horizon observations are only possible at sea, and are unavailable to the geographical explorer on land. The artificial horizon is a somewhat troublesome substitute, cumbrous in transportation and subject to provoking derangements. And of its availability in use, when in good condition, in exigencies of frequent occurrence with the traveler, Mr. Davidson furnishes the following illustrations: "The sun may be too high for observing double reflections with the ordinary sextant; the sun or a mountain may be too low to admit of available reflection in the artificial horizon; and in particular, these means positively fail when from any elevated point the traveler wishes to measure the depression of some object, as of the sea horizon, by which to determine his elevation or distance, knowing one of them; or, knowing the distance of another and lower mountain, to determine the difference of elevation. We have encountered all these difficulties, and also the less frequent one of falling in with a reef at night with the stars visible, but the sea horizon totally obscured in darkness."

Mr. Davidson's improvement consists in the use of an observing tube to which is attached, on the top, a small spirit level, the bubble of which is seen by reflection, in a manner which Fig. 140 will serve to explain. The observing tube is G G, which is supported by the exterior tube C; and this in turn is secured to the sextant by the screw M, which con-

nects with the ordinary telescope support. The ends of the tube G G are closed by plane glasses; a precaution apparently unnecessary. At W, on the top of the tube, is an opening, which permits the bubble of the level S to be seen by reflection from the mirror R, placed at an angle of forty-five degrees to the axis of the tube. As the level will be too near for distinct vision, a convex lens, L, is introduced into the tube between the mirror R and the eye; and this, by means of a screw-head exterior to the tube, may be advanced or withdrawn to accommodate different eyes. As the mirror R must not be permitted to cut off the view of the objects under observation, it has a breadth only equal to one-half the diameter of the tube. The lens L, also, is but a semicircle. All the half of the tube next the face of the instrument is clear. Fig. 141 is a cross-section, and shows this arrangement. It shows also that the spirit level is unsymmetrically placed on the top of the tube, being directly over the outer half, or that which is furthest from the face of the instrument.

Fig. 140.

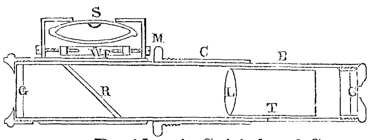
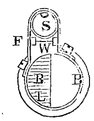


Fig. 141.



Davidson's Spirit-level Sextant.

The adjustment of this level is made either by changing the angle of the reflector, or by moving the frame carrying the cross-wires, or by elevating one end of the level itself; and it consists in making the image of the cross-wires bisect the image of the bubble when a distant object in the same horizontal plane and seen through the unoccupied half of the tube appears on a level with the image of the cross-wires. This adjustment is readily effected on land, may be made by means of the level itself, and is not easily deranged. Should it, however, become necessary to adjust the level at sea, the image of the cross-wires, when it bisects the image of the bubble, is made to appear on the same line with the visible horizon; and the correction for the dip of the horizon at the given height of the observer's eye is applied to all observed altitudes and depressions.

The index error may be determined when the level is adjusted on land, and used as a constant quantity for a not very extended series of observations, or it may be determined at sea whenever the horizon is visible, by observing the depression of the horizon and taking the difference or sum of the observed result and the computed dip for the index error.

The operation of making an observation for the altitude or depression of any object at sea or on land is as follows: Secure the level in its proper place on the instrument and hold the sextant in the usual manner, with the plane of its face in the vertical plane passing through the object and the observer. Looking through the tube, move the vernier arm until the image of the object is seen through the unoccupied half of the tube,

and bring that image into the same horizontal line with the image of the cross-wires at the time it bisects the image of the bubble, and if necessary note the time by chronometer. If the sextant and the level are in adjustment, the reading on the limb indicated by the vernier is the observed altitude or depression of the object.

Observations at night require the bubble to be illuminated. This may be done by means of a lamp; but Professor Frazer, of Philadelphia, has made the ingenious suggestion that a small tube containing phosphorus in oil may be placed over the level, into which the admission of air, when necessary, will produce all the illumination which the purpose in view requires.

Some judgment may be formed of the performance of this instrument from the following statement of actual observations made by Mr. Davidson in 1865.

Latitude from circummeridian altitudes of the sun with sextant and spirit-level horizon. Observations of November 11 *commenced* 5 *minutes* 48 *seconds before apparent noon, and ended* 18 *minutes* 18 *seconds after noon. November* 12 *commenced* 7 *minutes* 23 *seconds before, and ended* 5 *minutes* 55 *seconds after apparent noon.*

November 11, 1865.						November 12, 1865.					
$\overline{\odot}$			$\underline{\odot}$			$\overline{\odot}$			$\underline{\odot}$		
Deg.	*Min.*	*Sec.*	*Deg.*	*Min.*	*Sec.*	*Deg.*	*Min.*	*Sec.*	*Deg.*	*Min.*	*Sec.*
39	59	18	39	57	14	39	60	12	39	54	19
	55	55		57	36		59	28		56	37
	57	05		57	18		57	51		56	31
	56	52		58	41		57	39		58	13
	57	55		59	43		56	01		57	51
	55	52		61	27		56	59		58	29
	58	41		..	..		58	54		59	01
Means 39	57	23	39	58	38	39	58	09	39	57	17

These reductions have been unnecessarily made to seconds of arc that the actual working of the instrument may be seen; the probable error of one observation deduced from these series is one minute of arc, and the probable error of the mean of all the observations is thirty-five seconds of arc. This, of course, excludes whatever constant errors may have existed.

Mr. Davidson does not seem to have been aware that the expedient employed by him had ever been resorted to for a similar purpose before. In the Exposition of 1862 there were exhibited a number of modifications of the sextant designed to supersede the use of the artificial horizon, two of which resembling this are briefly described by the jury. Having stated that the novelties of this character present in the Exposition are reducible to three classes, viz: first, a spirit level, of which the bubble is reflected in the field of view; second, a pendulum either supported freely or immersed in fluid, having a horizontal arm that projects along

the line of sight; and, third, two independent floats with cross-arms, swimming in the same vessel of fluid; the jury go on to say that, in the first class, Messrs. Elliott Brothers, of London, " exhibit an arrangement of this kind, that is exceedingly light and compact. It is inserted within the eye-tube of an ordinary sextant telescope, and gives a remarkably clear bubble in the same field of view with the reflected object;" and that Mr. T. O. Buss, also of England, exhibits a similar construction, which is however somewhat more bulky, showing the bubble to the naked eye with much sharpness."

The pendulum contrivances mentioned by the jury were two; the first being "merely a small pendulum with two light arms which can be attached in front of the horizon glass, the arms appearing to coincide when the eye-tube is held horizontally;" and the second being " a massive appendage, consisting of a metallic chamber filled with oil in which the pendulum is suspended by a thin steel spring from a perforated axis through which the sight is taken, the turned up edge of the horizontally projecting arm appearing as a permanent horizon. The free movement round the perforated axis causes the edge to be parallel to the horizon, and that of the steel spring causes it to maintain a constant altitude."

In the instruments employing floats instead of a pendulum, (there was only one of this kind) an iron vessel containing mercury in two separate but communicating chambers, having glass walls, was attached to the face of the sextant. The line of coincidence of the floats when at rest gives the horizontal line. All these mechanical expedients are manifestly inferior to the optical contrivance of Mr. Davidson; who must, however, share the credit of the invention with the British inventors who brought it forward as early at least as 1862.

III—NAUTICAL COMPASSES.

Among instruments of this class there were exhibited one or two rather interesting novelties. In the Norwegian section appeared a ship's compass, the invention of Mr. B. F. de Wedel-Jarlsberg, designed to furnish automatically a kind of record of the course maintained by the vessel during any determinate period of time. The card, or rose, of this compass, carries at the center a small funnel communicating with a tube which runs from center to circumference and turns downward at the extremity. This tube revolves with the rose. Immediately beneath the extremity is a trough occupying the whole circumfrence of the instrument, and divided by partitions into compartments corresponding to the several points of the compass. Above the instrument is placed a kind of hopper containing small leaden balls, one of which is released every minute by a chronometric apparatus, and falling into the funnel is directed into the compartment which corresponds to the course which the vessel is at the moment pursuing. At the end of the time the num-

bers of balls in the several compartments will furnish the means of ascertaining the mean course of the ship, and also the greater or less regularity with which this course has been maintained. It is said that this compass has been found useful in actual navigation, and it is certainly worthy of attention by those whom it most concerns.

A nautical compass invented by Mr. E. S. Ritchie, of Boston, and exhibited by Mr. Duboscq in the French scteion, was noticeable as being a much more important improvement than the foregoing. The disadvantages of the common compass are three-fold, consisting, first, in the too great pressure upon the pivot, occasioned by the weight of the needle and card, and the consequent wear; secondly, the resistance opposed by friction to the directive force of the earth's magnetism; and thirdly, the agitation and oscillations produced by the motion of the vessel. Mr. Ritchie's compass is designed to provide a remedy for all these disadvantages. It presents to the eye an equal armed cross formed of hollow cylinders of thin metal, and carrying attached to the ends of the arms of the cross a circular ring, on which are inscribed the usual divisions of the compass; the whole being inclosed within a cylindrical box with a glass top, filled with an uncongealable liquid and suspended, as usual, in gimbals. The needle is contained in one of the two cylinders forming the cross; and these cylinders, containing only air, constitute a buoy, of which the weight is so adjusted that the pressure of the system upon the pivot is reduced to a few milligrams. The deterioration from wearing is consequently, for long periods of time, almost insensible; and the resistance of friction to the traversing of the needle is a minimum. But perhaps a more important advantage, as it regards the preservation of the points in contact, and as it regards the steadiness of the indications of the needle, results from the fact that the whole moving system is of so nearly the same specific gravity as the liquid in which it is immersed as to make both participate equally in the movements caused by the rolling and tossing of the vessel, or the working of the engine, and to allow of no differential motion between the needle and its pivot. Thus a serious source of unsteadiness and of wear is effectually removed. In order to prevent any injurious effect from following the changes of temperature to which the instrument is liable to be subjected, there is attached to the bottom of the box a small metallic chamber with elastic walls, like the box of an aneroid barometer, keeping the compass-box always full but maintaining the inclosed liquid at a constant pressure. This instrument has been thoroughly tested on board of many American vessels, and the numerous certificates of its admirable performance, and of its great superiority to the ordinary compass, especially in rough weather, which have been addressed to the inventor by navigators of experience, leave no doubt of the great practical value of the improvement.

IV.—DEEP-SEA SOUNDING.

The difficulty and uncertainty attending deep-sea soundings with the ordinary lead and line, have led to the suggestion of many devices designed to secure a higher degree of accuracy. The sounding line, drifting under the influence of the currents which prevail far beneath the surface of the sea, will often continue to run out long after the lead has struck the bottom, so that the moment of striking cannot be detected; and the depth inferred from the operation will inevitably be in excess of the real depth. Moreover the resistance opposed to the descent of the lead by the friction of the line in the water continually increases as the length of the line increases, and the velocity of the descent correspondingly diminishes; so that, at the depth of about two thousand fathoms, this resistance becomes equal to the gravitating force, and the descent is arrested altogether. This difficulty cannot be effectually overcome by indefinitely increasing the weight, for the weight must not exceed the tensile strength of the line; otherwise the line itself will ultimately part and the lead will descend without it. The extent to which the results of deep-sea soundings are affected by the considerations here mentioned, and the absolute impossibility of receiving as correct the reports which have from time to time been made by navigators of casts of the lead without finding bottom to depths of five, seven, and even nine miles, were first, as it is believed, pointed out by Professor W. P. Trowbridge, now of New York, in the Reports of the United States Coast Survey, and in the American Journal of Science and Arts, in 1858.

TROWBRIDGE'S DEEP-SEA APPARATUS.

Professor Trowbridge proposed a simple and very effectual mode of overcoming all the difficulties which have hitherto perplexed the problem of deep-sea sounding, and of reaching in all cases results entirely trustworthy. This consists in inclosing the line itself, wound in balls which uncoil from the center, in a hollow cylindrical case, and sending it down along with the lead; the end only being secured to the boat occupied by the observers. The force required to uncoil the line is entirely insensible, there is no dragging of the line through the water, and the descent of the lead is rapid and uniform from first to last. Lateral currents will have no influence on the vertical velocity. What this velocity should be may be calculated theoretically, and, for greater security, what it actually is may be determined, once for all, experimentally. After this, the time observed to elapse between the throwing of the lead and its striking the bottom, becomes an accurate measure of the depth. It is necessary, therefore, that the observer should be able to note exactly the moment of impact of the plummet upon the bottom. In order to do this the sounding line of Professor Trowbridge's apparatus contains a fine insulated wire connected with an alarm or with a

chronoscope in the boat, and also with a battery. The impact of the lead on the bottom completes an electric circuit, and the time required thus becomes known. This part of the apparatus was invented as early as 1845; but inasmuch as the descent of the lead, in the old mode of sounding, was not at all uniform, the contrivance had no other value except to notify the observers at what moment they might begin to haul back the line. Moreover, the great strain upon the line in that mode of practice had a tendency to break the insulation, and the method was employed no further than to test its practicability.

It is to be observed, however, that the really important part of Professor Trowbridge's invention, which consists in the expedient by which the resistance opposed by the friction of the line to the descent of the lead is prevented, is not dependent for its practical availability upon the observation of time, or upon the use of electricity. A method was both proposed and employed by him for determining depths by attaching to his apparatus containing the line, a pair of Saxton's improved "current-meters." The current-meter of Saxton is a delicately pivoted helix which is turned by the water through which it passes, as a boy's wind, mill is turned by the air, and which records the number of its revolutions upon a set of registering dials. In sounding, it is necessary to employ two such helices, turning in opposite directions, for the purpose of eliminating any error which might arise from the rotation of the whole apparatus in consequence of the twisting of the line or other disturbing cause. It is necessary, also, to provide that so soon as the plummet makes contact with the bottom of the sea, the helices shall be thrown out of gear with their registers. On hauling them back, the depth from which they have been recovered will be ascertained by taking the mean of the two records.

Helical current-meters have been employed in sounding by the ordinary method; and in fact, for sounding in deep seas, they have been regarded as indispensable, in consequence of the great errors likely to arise from the drifting of the line, or from its continuing to run out after the bottom has been reached: but the form of helix employed has been that known as Massey's, in which the wings are attached to a bulky central axis, and of which the indications have not been found always consistent with themselves. The current-meter of Saxton performs in a manner very much more satisfactory.

In sounding at extreme depths by this method, or indeed by any method, it need hardly be said that the plummet itself cannot be recovered; for in hauling back, the line has to overcome the friction of its whole length as well as the weight of the lead: and since this weight alone is all that it is able to bear, it necessarily parts when the strain is doubled. But by an automatic detachment of the sinking weight at the bottom, the lead may be so lightened that the apparatus for registration may generally be brought back safely. A contrivance for effecting such a detachment was first introduced by Lieutenant J. M. Brooke,

of the United States navy, in 1857, which may be found described in "Maury's Sailing Directions," published under authority of the Navy Department in 1858. The object which Lieutenant Brooke had in view was to obtain specimens of the deposit at the bottom of the sea. In order to do this, the sinker employed was a thirty-two pound shot, perforated through the center. Through this perforation passed an iron tube projecting below, and into the extremity of the tube were introduced a number of quills, which, as the tube struck the bottom, became filled by the pressure, and were brought safely up filled with the ooze. Another apparatus, very much resembling this, was invented by Commander B. F. Sands, now Commodore Sands, in charge of the United States Naval Observatory, about the same time. In this case the design was to permit the recovery of the Massey helix.

SOUNDING WITHOUT A LINE.

The possibility of sounding without a line has occupied the attention of many persons interested in this subject. All such schemes involve, of course, the ascent of the apparatus by its own buoyancy, after the detachment of the sinking weight. But the difficulties in the way of their practical success have been generally regarded as too great to be overcome. In the first place, no solid buoy is available for the purpose, since there is no solid which is buoyant in water, and which is at the same time free from liability to be compressed in the deep sea to a density so great as to prevent it from returning. In the next place, no hollow buoy of metal will answer, since in order that a metallic vessel may be strong enough to resist collapse, it must be made too thick to be buoyant. Glass has been proposed as a material suitable for the purpose, by the inventors of an apparatus presently to be mentioned; and these gentlemen state that spherical glass buoys have been subjected by them to a pressure of seven tons to the square inch, without being crushed. Such a pressure corresponds to a depth of about six miles; and accepting the statement as correct, we may regard this part of the problem as having been practically solved.

There are other difficulties, however, of which the same remark cannot be made. It will be of no avail that the sounding apparatus returns to the surface, unless it brings back with it some trustworthy indication of the depth to which it has been submerged. Such an indication, it has been supposed, might be afforded by a pressure-gauge adapted to register the maximum hydrostatic pressure to which the apparatus has been subjected. There is room, however, for serious doubt whether any form of gauge which has yet been suggested, can be relied on satisfactorily to fulfill this condition. This question has occupied much attention on the part of those who have studied the subject of deep-sea sounding, and the conclusion has generally been unfavorable. It is probable that the experiments of Perkins, published in the year 1820, first suggested the possibility of ascertaining depths by a method founded on the compres-

sibility of water; but the fact that a change of temperature of a single degree centigrade produces a much larger change in the volume of water than an increase or diminution of pressure by an entire atmosphere, and the additional fact that the law governing the relations of temperature to volume is inverted between thirty-two and forty degrees Fahrenheit, have discouraged most persons from attempting to follow out this idea. In the Exposition of 1862, nevertheless, a deep-sea pressure-gauge was exhibited by Mr. H. Johnson, a British inventor, which was essentially a reproduction of the form of apparatus originally devised by Mr. Perkins. The jury remark of it that, in practice, a correction must of course be applied for change of temperature. The difficulty is to know what *is* the temperature at the greatest depth, since that is not necessarily the minimum.

But further than this, it is to be taken into account that the compressibility of water is itself variable with the temperature, being, according to the most recent determinations by Grassi, fifty-one and a half one-millionths of the total bulk per atmosphere, at 1.5° C, and only forty-six one-millionths at 18° C, becoming still less as the temperature rises. In the absence of any knowledge of the actual temperature at the bottom of the sea, this circumstance alone, and without reference to the fluctuations of volume occasioned by thermal changes, would render the determination uncertain to the extent of possibly one-tenth of the entire depth. As a security against this error there is no protection but that which is afforded by the doubtful indications of the minimum thermometer.

An additional objection is found in the consideration that the *time* which elapses between the dispatch and return to the surface of the sounding apparatus will be so great that, except where there are no subaqueous currents—that is to say, except under conditions which nowhere exist—the point at which the float will reappear will be very far from that occupied by the observers. It is hardly necessary to insist on the difficulty of detecting a very small object which may be afloat upon the waves anywhere within a radius of two or three miles. It is a necessity of the case that the object should be small, for whatever increases its bulk diminishes relatively the accelerative force with which it ascends, protracts the duration of its absence, and adds proportionally to the extent of the area over which it must be sought for. It has occurred to every one who has thought upon this subject, that something might be gained to the conspicuousness of the object, by providing it with reflecting surfaces, analogous to those of the scintillating signals used in geodetic operations; but after making every allowance for the degree of possible effectiveness to be anticipated from this expedient, practical men have been inclined to consider the objection fatal.

How far this conclusion is reasonable, may be inferred from the following considerations. The time occupied by the apparatus in the descent and return is ascertainable by applying the formulæ of Dubuat

expressing the laws of motion of sinking bodies as deduced from actual experiment. Applying these formulæ to the question under consideration, Professor Trowbridge (American Journal of Science, 1858) has shown that, in the case of a sphere, the velocity becomes very soon uniform—for a cannon shot of thirty-two pounds, for instance, in less than three seconds—and that the value of this uniform velocity will be expressed by the equation,

$$V=2\sqrt{\frac{gW}{SD}},$$

In which V represents the velocity sought, in feet; W the weight in water of the body expressed in pounds avoirdupois; S the horizontal cross-section in square feet or fractions; and D the density of the liquid expressed by the weight avoirdupois of a cubic foot; while g represents, as usual, the force of gravity. For a thirty-two pound shot W will have an effective value of 23.38 pounds, and S will be 0.21 square foot. D in sea-water will be 64.2 pounds, and g is 32.189 feet. Substituting these numbers in the formula, the sinking velocity will be found $=16.21$ feet.

In order to secure this velocity or a greater against the resistances of the sounding apparatus arising from its buoyancy and friction, the weight must be increased. Taking it, however, at sixteen feet, the apparatus will sink to the depth of five miles in twenty-seven and a half minutes—say half an hour. The return will be much slower, since the ascending force will be equal only to the weight of the water displaced by the buoy, diminished by its own weight and that of the attached apparatus in water. Supposing the buoy to have the same dimensions as the thirty-two pound shot, or a diameter of six inches and a fifth, it will displace a weight of water equal to 4.624 pounds. Its thickness must be sufficient to resist the crushing pressure of the deep seas—say at least half an inch. The weight in water of its solid material will, therefore, be more than a pound and a half, which will diminish its effective buoyancy to three pounds; and to this reduction must be added the weight in water and the frictional resistance of the attached apparatus, which will be equivalent, perhaps, to a pound additional. The buoy, therefore, will have an upward tendency which may be measured by a constant pressure of two pounds. Substituting this for W in the formula foregoing, we shall find that the uniform ascending velocity will be four feet and three-eighths; and the time of ascent from a depth of five miles will be one hour and forty minutes. Thus the total time of descending and ascending in a sea of the depth supposed, will exceed two hours. During so long a period, the apparatus could not fail to drift very widely.

THE BATHOMETER.

In the present Exposition an instrument has been exhibited in the American section, by Messrs. Sidney E., and G. Livingston Morse, of

New York, which is called by them a bathometer, and which, as its name implies, is designed to determine the depths of the waters of deep seas. The instrument is described by its inventors in the words following:

"This invention consists in general terms in measuring the depth of water by the compression of a fluid or fluids contained in a vessel sunk by a weight, which is automatically detached from the rest of the apparatus on striking bottom, allowing the vessel and its other accompaniments to be raised by a buoy, the apparatus being sunk without any connection with a line, and the buoy being provided with a signal to enable the operator to discover it when it ascends to the surface of the water.

"In carrying out this invention, take a glass bottle, say about five or six inches long, and of such interior diameter that its capacity exclusive of any solid substance and of the mercury and air it may contain, shall be about five cubic inches; take also a glass meter tube about seven or eight inches long, open at both ends, with a bore of about one-fifth of an inch in diameter; let this tube be swelled near the upper end and the swelled part ground into a stopper to fit the neck of the bottle; pour into the bottle mercury to a level with the lower orifice of the meter tube and enough more to fill the meter tube once; then fill the bottle with water and insert the meter tube so that the swelled part or ground glass stopper shall be fitted perfectly tight into the neck of the bottle; take then a thin India-rubber tube five or six inches long and draw it over the outer end of the meter tube and fasten it, fill the rubber tube with water, and fasten it by winding and tying a cord around the tube; it will then form a bag of water, and it should be long enough to hold a quantity of water at least sufficient to fill the meter tube once. A scale is to be adapted to the meter tube. When the instrument is ready for operation the water or lighter fluid will completely fill the meter tube. If the instrument is now sunk in deep water the external pressure of the water as it descends will cause the fluids in the India-rubber bag, the meter tube, and the body of the vessel to contract, and will force the water in the meter tube through the mercury into the body of the vessel to supply the vacancy caused there by the compression of its contents. On the return of the instrument to the surface the expansion of the fluid or fluids in the body of the vessel under the relaxation of the external pressure during the ascent will force the mercury into the meter tube to the amount of their greatest compression, thereby indicating the degree of that compression and by inference the depth to which the instrument has descended. The instrument is rendered more sensitive and more applicable for measuring depths not exceeding 500 feet by the introduction of a minute quantity of air or other elastic fluid into the vessel containing the liquids. The liquids can easily pass each other in the bore of the meter tube, thereby enabling the operator to restore them to their original position for a new operation merely by turning the instrument. A bag of India-rubber or other suitable flexible material is attached to the outer end of the meter tube for the pur-

pose of preserving the exact quantities of the fluids in the vessel as at first adjusted and of enabling the operator by pressure upon the bag to discharge the contents of the meter tube into the vessel, and therefore to use a meter tube of small bore. A buoy and weight is attached to the instrument by any suitable self-detaching device, so that when the instrument or its appendage touches the bottom the weight shall be detached and allow the buoy to carry the instrument to the surface, thereby dispensing with a line. The submerged buoy is released by causing a small weight attached to the long arm of a lever to support on the short arm a larger weight which sinks the buoy till the smaller weight by touching the bottom is supported thereon, thus causing the short arm no longer counterpoised to fall and discharge the weight. A rod or pole is attached to the instrument, so that on its return to the surface of the water it will attract attention at a distance, so as to facilitate the recovery of the apparatus of which it forms a part.

"The upper end of the rod should be prepared with small pieces of bright tin, polished metal, silvered or colored glass, or other substances which will reflect the light and attract attention from a distance. For greater accuracy in deep-sea soundings the bathometer should be surrounded by melting ice to keep the bottle and its contents at (32° F) a fixed temperature. The buoy used is of glass, this being about the only material which will resist the immense pressure of a column of water miles in height and retain its buoyancy. A glass sphere in the United States Patent Office has withstood the pressure of seven tons on the square inch. It floats more than half out of water."

In this description mention is made of only a single buoy, but the figure of the apparatus which accompanies the description represents three buoys of spherical figure inclosed one above another in a cylindrical case having rounded ends. The model buoy deposited at the Patent Office has a diameter of about five inches. According to the foregoing statement of the inventors, this sphere floats half out of water. Its force of buoyancy is therefore equal to half the weight of the water which it displaces when submerged, and this will be expressed by the equation $F=\frac{1}{2}\times\frac{1}{6}\pi d^3\times 64.2=1.216$ pounds. Multiplying this by three, we have as the total ascending force of the three spheres, 3.648 pounds, which is to be diminished by the weight in water of the apparatus to be raised and its enveloping cylinder, and the friction of the water upon the extended surface of the cylinder. The available force can hardly, therefore, exceed two and a half pounds. The cross-section of the cylinder will, moreover, be not less than five and a half inches, and substituting these numbers in the formula for velocity as before, we shall obtain as the velocity of the ascent five and a half feet. With this velocity the apparatus would reach the surface from a depth of five miles in one hour and twenty minutes, making the whole time of ascent and descent more than an hour and three quarters. By varying the number and dimensions of the buoys, the duration of the operation may be within certain limits varied, but it will always be great. The diameter

of the buoy cannot be indefinitely increased, since a point will soon be reached at which sufficient strength to resist the pressure can only be secured at a total sacrifice of buoyancy.

The plan proposed by the inventors of the bathometer to secure constancy of temperature by surrounding the instrument with ice is one on which it would be hardly safe to place reliance. If the quantity of ice employed is considerable, its bulk will materially retard the velocity of descent, and by protracting the time of exposure endanger its liquefaction. If it is small, liquefaction will be inevitable. The rapidity of liquefaction will, indeed, be very sensibly accelerated by the hydrostatic pressure; since it has been demonstrated by Mr. James Thompson that the freezing point is depressed, as pressure increases, by such a law, that, under a pressure of eight hundred atmospheres—that is to say, at a depth of five miles—the effect amounts to not less than six degrees Centigrade, or eleven degrees Fahrenheit. Still, it must be admitted that if it shall be found possible to maintain an ice bath surrounding the instrument long enough to carry it safely through the depths at which in going and returning it is liable to be subjected to perturbations from varying temperature, an essential point will be gained.

Turning now to the peculiarities of construction of the bathometer itself, it may be questioned whether the form of pressure gauge proposed by them has any advantages over that of Perkins, recently revived with modifications by Johnson. The introduction of a second fluid, viz: mercury, which is itself to some extent compressible, while it increases the complication of the apparatus, adds a new element to the uncertainty of its indications. The admission of air for the purpose of increasing the sensitiveness of the indications is still more objectionable. The presence of two compressible bodies having co-efficients of elasticity so widely different as air and water in the same pressure gauge, would give rise to great inequalities in the scale; while the disturbing effect of temperature on air would be immensely greater than that which it produces in water. Moreover, if the instrument is to be made serviceable, the proportions of the liquids which it contains should never on any account be in the slightest degree altered.

Supposing, however, that these difficulties should prove not to be insurmountable, it may be suggested that probably the dimensions given to the different parts of the instrument might be advantageously modified. From the actual dimensions as given above, it may easily be computed that the index reading corresponding to an atmosphere of pressure will be only 0.008 inch. This is too small a difference to be read easily in a barometer, and must be still more difficult in an instrument unprovided with any zero correction for the varying level of the mercury in the reservoir. It is much to be desired that a simple and entirely trustworthy method of deep-sea sounding, free at the same time from practical difficulties, should be devised and brought into general use. The plan of Professor Trowbridge seems at present to be that which has most nearly resolved this important problem.

CHAPTER XVIII.

METROLOGY AND MECHANICAL CALCULATION.

MEASURING RULES—DIVIDING INSTRUMENTS—CATHETOMETERS—SPHEROMETERS—COMPARATORS—MICRO-PANTOGRAPHS—FROMENT'S—HARDY'S—PETERS'S—PLANIMETERS—OPPIKOFFER'S—AMSLER-LAFFON'S—MECHANICAL CALCULATION—THE ARABIC NUMERALS—COUNTING MACHINES—CALCULATING MACHINES—GERBERT—ALBERTUS MAGNUS—ROGER BACON—NAPIER—HIS RODS—LOGARITHMS—PASCAL'S CALCULATING MACHINE—LEIBNITZ'S—GUNTER'S LOGARITHMIC RULES—LEBLOND'S—GATTEY'S—CALCULATING MACHINE OF OPRANDINO MUSINA—OF THOMAS DE COLMAR—CAPABILITIES OF THIS MACHINE—BABBAGE'S DIFFERENCE ENGINE—SCHEUTZ'S—BABBAGE'S PROJECTED ANALYTIC ENGINE.

I—MICROMETRY.

Under this head may be classed not only instruments for the direct measurement of dimensions of length to the last extreme of accuracy, but also instruments for making the minute divisions of rules and circles, for determining the curvatures of surfaces, and for reducing designs of sensible magnitude to microscopic dimensions.

MEASURING RULES.

Several admirable standard meter rules were exhibited by Dumoulin-Froment and by Deleuil, of Paris, and also by Breithaupt, of Cassel. That of the first exhibitor above named was divided to half millimeters on a silver surface, and read by a vernier to one two-hundredth millimeter. Beautiful rules of wood, brass, and ivory were exhibited by many manufacturers, but especially by Elliott Brothers, of London. The admirably divided steel rules of Messrs. Darling, Brown & Sharpe, of Providence, Rhode Island, attracted also much attention.

DIVIDING INSTRUMENTS.

Dividing instruments were exhibited by Dumoulin-Froment and by Perreaux, of Paris, which, in respect to workmanship and precision, seemed to have exhausted the resources of art. The circular dividing machine of Mr. Perreaux consists essentially of a strong horizontal circular plate, designed to carry the circle to be divided. This bed-plate is toothed at its circumference and is driven by a tangent screw. The tangent screw is provided with a large circular head having a system of stops by which it may be arrested at a given fraction of a revolution, or allowed to make several revolutions before stopping. A horizontal metallic rod extends across the center of the circle, and to this the dividing apparatus is attached. This apparatus is movable on the rod, and may be fixed at any distance from the center, in order to accommodate circles of different diameters. Another adjustment permits it to be arranged so as to divide, if necessary, on a bevelled limb. The dividing

tool is drawn back by hand, and returning performs its cut by the action of a spiral spring. As the lines marking the divisions are generally of the same length, but are periodically longer, as for instance at the fives and tens, the carriage of the tool is furnished with wheels having notches in the circumference, which, turning as the work advances, give, at the required intervals, the necessary increase of range.

The machines for straight line division have a horizontal cast-iron bed on which the rule to be divided is fastened, and along which the carriage of the tool is driven by means of a screw resembling the screw of an engine-lathe. In Mr. Perreaux's machine the screw is of steel, and has a thread of half a millimeter. The head of this screw has divisions and stops resembling those of the machine above described for circle dividing; and the dividing tool is operated in a manner entirely similar.

A small dividing instrument for ruling microscopic divisions was exhibited by Mr. Perreaux in an unfinished state. This machine has a screw of two decimeters (eight inches) in length, four millimeters in diameter, and one-tenth of a millimeter thread. The head of the screw is a ratchet of ten centimeters in diameter, having 300 teeth. Each tooth advances therefore the ruling tool one three-thousandth of a millimeter. This corresponds to about 78,000 lines to the inch. It remains to be tested how far the expectation of the constructor will be realized. Mr. Nobert, of Barth, Pomerania, has ruled microscopic bands with lines as close as 120,000 to the Paris inch, or more than 112,000 to the English inch. He has never made known the construction of the mechanism by which he does this; and though his name was on the list of exhibitors from Prussia, he failed, to the great regret of all visitors acquainted with the results which his extraordinary skill has enabled him to achieve, to make his appearance.

CATHETOMETERS.

Mr. Perreaux exhibited also a cathetometer, or instrument for vertical linear measurements, of the construction which he has already made so widely and so favorably known. This instrument consists of a tube of brass, turning on a vertical steel axis which it incloses, and which is fixed in a solid tribrach of iron furnished with leveling screws and levels. The tube is provided on two opposite sides with vertical ribs or guides, along which a carriage slides up and down, carrying a telescope with delicate level attached, and also, sometimes, a dividing tool. The carriage may be clamped at any altitude, and when clamped, may be moved slowly by means of a micrometric screw. The tube is graduated and the carriage has a vernier, by means of which the reading may be carried to the two-hundredth part of a millimeter.

SPHEROMETERS.

Mr. Perreaux also exhibited a spherometer, or instrument for measuring the curvature of surfaces. It may also be employed for determining the thicknesses of very thin plates of any solid substance. The original

spherometer consisted of a three-armed frame standing on three vertical steel pins forming with each other an equilateral triangle. In the center of the instrument a vertical screw with fine thread, having a large divided head, is turned downward until the point reaches the surface on which the instrument stands. If this surface is truly plane, the graduation should be such that the index under these circumstances will mark zero. On placing the instrument upon a spherical surface, whether convex or concave, and again making contact, the corresponding positive or negative reading will indicate the degree of sphericity. This construction renders the use of the instrument somewhat difficult, and leads to some uncertainty as to the results of observations. In Mr. Perreaux's spherometer the central screw is perforated longitudinally throughout its axis; and through the perforation thus formed passes a slender rod of steel held in position only by slight friction. The top of this rod expands into a knife edge, and across it lies, above the screw, a lever which is attached at one end very near to the knife edge, to a stud in the screw-head, by a joint. It is evident that if the screw goes up or down carrying the rod with it, the horizontality of the lever will be undisturbed. But if the screw goes down while the rod stops, the free end of the lever must rise. This is what must happen when, in the use of the instrument, contact is made with the surface under examination. The moment of contact is thus detected with great accuracy. In order to increase the sensitiveness of the instrument, Mr. Perreaux has introduced a second lever which is acted on by the first. The extreme delicacy of the determinations of which it is thus made capable is truly surprising.

A spherometer of great ingenuity and delicacy was also exhibited by Mr. Julian Giordano, of Naples, in the Italian section, in which the contact of the central screw was determined by the passage of a galvanic current giving an alarm. It was called by him the electric spherometer.

COMPARATORS.

Comparators are instruments for ascertaining the agreement or disagreement of two measures having nominally the same length. In appearance they present some resemblance to the machines for dividing right lines. A horizontal bed of cast iron is provided to receive the rules to be compared. These rules may be constructed so as to include the required length between their extreme terminal surfaces, in which case they are then called measures *à bout;* or they may be so formed that the length shall be limited by lines traced upon the lateral surface of the rules, and they are then called measures *à trait.* Measures *à bout* are placed between the short arms of two "contact levers," the long arms carrying verniers which traverse nicely divided arcs and which are read by microscopes. The support of one of these levers is firmly fixed to the base of the machine; that of the other is attached to a sliding carriage by means of which it may be placed at the suitable distance from the first and clamped. This support is also commanded by a micrometric slow move-

ment produced by a longitudinal screw of fine thread having a large divided circular head. The rule being in position, the vernier of the fixed lever is first brought to zero. This is accomplished by a slow movement of the rule itself with the bed on which it rests. The vernier of the movable lever is afterwards brought to zero by moving the support of the lever through the instrumentality of the micrometric screw above mentioned. The length of the rule is then given by reading, for the larger divisions, a longitudinal scale which the sliding support of the lever traverses; and for the fractional subdivisions, the dial of the screw head. In general, when a rule is to be compared with a standard of the same nominal length, the larger divisions may be neglected as being the same for both, and the dial of the screw head only read. In this case the two rules must of course be examined successively; and the difference of the readings of the dial will be the difference of their lengths. The value of one division of the dial in Mr. Perreaux's comparator for meters or longer bars is one four-hundredth of a millimeter. Mr. Silbermann's comparator at the *Conservatoire des Arts et Métiers* reads to one one-thousandth of a millimeter. In determining differences so minute, it is indispensable to take into account the temperature of the instrument and that of the rule at the time of observation, and to reduce the observed length to what it should be at a standard temperature, by allowing for the effects of expansion or contraction. Even the results obtained by such reductions are not always satisfactory; since it is rare to find two bars of the same metal to which the same coefficient of expansion will severely apply. The mode of observation most certainly to be relied on is that in which the whole instrument, including the rule, is immersed completely in a bath of melting ice.

It sometimes happens that the terminal surfaces of a bar are not exactly parallel. In this case a measure *à bout* will give different results according as the contact levers are applied in the middle or near the sides. Mr. Perreaux's comparator is provided with the means of testing the accuracy of this parallelism. The whole bar may be moved laterally by means of two entirely similar screws, one near each end, which turn with the same angular motion. In this slow progress, if the verniers of the two levers indicate no change of reading, the surfaces are inferred to be parallel. If one or both the readings change, the amount of change will indicate the amount of inaccuracy.

When the reading is *à trait* the contact levers are unnecessary. For the examination of bars of this description two microscopes are employed, placed vertically over the bar upon the bed of the comparator, each being provided with a micrometric eye-piece. The manner of making comparisons in this case requires no particular description.

For the comparison of the subdivisions of a scale throughout its length, with the view of testing their uniformity, two microscopes are fixed to a common sliding base and are brought to include between them any determinate number of divisions. By the movement of the com-

mon base from end to end, it will easily be determined whether the same number of divisions on the scale corresponds everywhere to the same absolute space, and if not, what and how great are the irregularities. For the purpose of varying the test, the distance between the two microscopes upon their common base admits in the comparator of Mr. Perreaux of being increased or diminished to any extent between the limits of five centimeters and twenty centimeters.

A similar comparison may be made between the divisions of two scales, which are both of them at the same time on the bed of the comparator. In order to effect this one of the two microscopes must be advanced beyond the other, in a direction at right angles to the length of the scale, to such a distance that while one of them reads the standard the other reads the scale to be tested. In such a comparison it is well to place the microscopes as near together as possible, and having brought one of them truly over the first division of the standard, to move the scale under scrutiny longitudinally until its first division comes truly under the other. Then, as the microscopes are both advanced by the movement of their common base, the readings of the two ought to be constantly the same, and the differences of reading will indicate the amount of disagreement. If the standard is known to be absolutely correct these disagreements will be the errors of the rule under examination. If the standard has errors, these, of course, ought to be known, and the errors of the rule on trial will be deduced by a proper combination of these with the observed discrepancies.

In the exposition of Mr. Dumoulin-Froment there was exhibited a new form of comparator constructed according to the designs of Mr. Tresca, of the *Conservatoire des Arts et Métiers*, which promises considerably to expedite comparisons. In this but one microscope is used, and both rules to be compared are placed side by side upon the bed. The whole bed of the instrument is movable upon nicely-constructed ways, both longitudinally and laterally. One end of the standard is first brought truly under the microscope, and then, by the lateral movement, the scale on trial is brought in turn into the field of vision, and subsequently, by the slow movement of this scale itself, if necessary, its mark of verification is brought to the cross-lines of the instrument. These adjustments having then been verified, the whole system is moved longitudinally until the opposite ends of the bars come under observation. Without disturbing the microscope the mark on the standard is first brought to the cross-lines, and subsequently, by the lateral movement again, the other bar is brought into view, when the differences of length, if any, may be measured by the micrometer. This is a great simplification upon the comparators heretofore in use. Its performance in practice will be looked for with interest.

MICRO-PANTOGRAPHS.

Of micro-pantographic instruments there was but one exhibited, which was in the exposition of Mr. E. Hardy, of Paris. The first micro-pan-

tograph for engraving on glass ever constructed is believed to have been that of the celebrated Froment, whose son-in-law, Mr. Dumoulin-Froment, still honorably maintains the high reputation so long enjoyed by him. In principle, this instrument is extremely simple. The wonderful part of it is the almost miraculous accuracy of workmanship which preserves in movements inconceivably small a severe accuracy of proportions not easily secured in instrumental drawings even of considerable dimensions. The essential part of the instrument is a vertically-suspended lever, pivoted near the upper extremity in a universal joint. If this lever moves in its pivots the two extremities describe similar figures, but these figures are unequal in dimensions in the same proportion as the lever arms are unequal. And accordingly, if the lower extremity be made to trace out the characters of an inscription or the lines of a drawing, the upper extremity will perform all the motions necessary to produce a similar drawing or inscription reduced, and of which the scale of reduction will depend upon the relative lengths of the arms. In the ordinary pantographs the lever which produces the drawing carries a pencil which moves with it. In the micro-pantograph it is the glass receiving the drawing or inscription which moves, while the tracer which cuts the lines, and which is a fragment of diamond brought to an exceedingly fine point, remains motionless.

With a single lever it is possible to make a reduction in the ratio of one or two hundred to one. But by employing a second lever to act upon the first a larger reduction may be secured, of which the ratio will be found by compounding the ratios of the two successive reductions. The instrument exhibited by Mr. Hardy appeared to have but one lever. In the Exposition of 1862, however, there was exhibited an instrument of similar description, in which, by a combination of two levers, the reduction was carried to the extraordinary extent of six thousand two hundred and fifty diameters. In this machine, invented and constructed by Mr. W. Peters, of London, the levers were so contrived as to allow the scale of reduction to be varied at pleasure, from the extreme limit just mentioned down to one hundred and ten diameters, according to the character of the work to be done. The following extract from the account of this instrument, given by Dr. Brooke, in the jury report on the instruments of precision exhibited in that Exposition, will be read with interest as illustrating its almost miraculous powers:

"The lower end of the lower lever carries a pencil or tracer connected with it by two equal and parallel links, which is passed by the operator's hand over the design or writing to be copied. The upper end of the upper lever carries the piece of glass for the reception of the diminished copy. Over the glass is mounted a diamond, pointing downwards, which remains stationary while the glass moves under it, the usual process of writing being here reversed. Mechanism is connected with the diamond, by means of which it can be raised or lowered, and also pressed with greater or less force upon the glass; and so efficient are these contriv-

ances that the thick and thin strokes of ordinary writing can be faithfully transferred to the minute copy on glass.

"A full and lucid description of this most interesting machine, of which the above is but an outline, is published in the transactions of the microscopic society in the form of a paper by its president, R. J. Farrants, esq., read 25th April, 1855; and some further particulars are given in the president's address to the same society, delivered 12th February, 1862.

"The following statements of its powers which, on inferior authority would hardly be credited, are given by Mr. Farrants:

"'The name and address of Mr. Mathew Marshall, Bank of England, have been written in $\frac{1}{2500000}$ of an inch, the two and a half millionth part of an inch. The Lord's Prayer, too, has been written, and is legible, in the $\frac{1}{356000}$ of an English square inch. The measurements of one of the specimens were verified by Dr. Bowerbank, with a difference of not more than one five-millionth of an inch, and that difference, small as it is arose from his not including the prolongation of the letter *f* in the sentence "deliver us from evil;" so he made the area occupied by the writing less than that stated above. Some idea of the minuteness of the characters in these specimens may be obtained from the statement that the whole Bible and Testament in writing of the same size might be placed twenty-two times on the surface of a square inch. The grounds for this startling assertion are as follows: The Bible and Testament together in the English language, are said to contain 3,566,480 letters. The number of letters in the Lord's Prayer, as written, ending in the sentence "deliver us from evil," is 223, whence as $\frac{3,566,480}{223} = 15,922$, it appears that the Bible and Testament together contain the same number of letters as the Lord's Prayer written 16,000 times; if, then, the prayer were written in $\frac{1}{16000}$ of an inch, the Bible and Testament in writing of the same size would be contained by one square inch; but as $\frac{1}{356000}$ of an inch is one twenty-secondth part of $\frac{1}{15922}$ of an inch, it follows that the Bible and Testament in writing of that size would occupy less space than one twenty-seventh of a square inch.'

"It only now remains to be seen that, minute as are the letters written by this machine, they are characterized by a clearness and precision of form which proves that the moving parts of the machine, while possessing the utmost delicacy of freedom, are absolutely destitute of shake, a union of requisites very difficult of fulfillment, but quite indispensable to the satisfactory performance of the apparatus."

More interesting, perhaps, than the excessively minute inscriptions above mentioned, if not to the same degree marvelous, are the microscopic copies of drawings and designs executed by the same ingenious mechanism. These are reduced from any subjects which may be proposed with remarkable expedition and with admirable fidelity. There is in the possession of the writer a copy of the device borne by the seal of Columbia College, New York, executed for him by Mr. Dumoulin-Fro-

ment, within a circle less than three one-hundredths of an inch in diameter, in which are embraced four human figures and various other objects, together with inscriptions in Latin, Greek, and Hebrew, all clearly legible. In this device the rising sun is represented in the horizon, the diameter of the disk being about one three-thousandth of an inch. This disk had been cross-hatched by the draughtsman in the original design from which the copy was made; and the copy shows the marks of the cross-hatching with perfect distinctness. When this beautiful and delicate drawing is brought clearly out by a suitably adjusted illumination, the lines appear as if traced by a smooth point in a surface of opaque ice.

II.—PLANIMETRY.

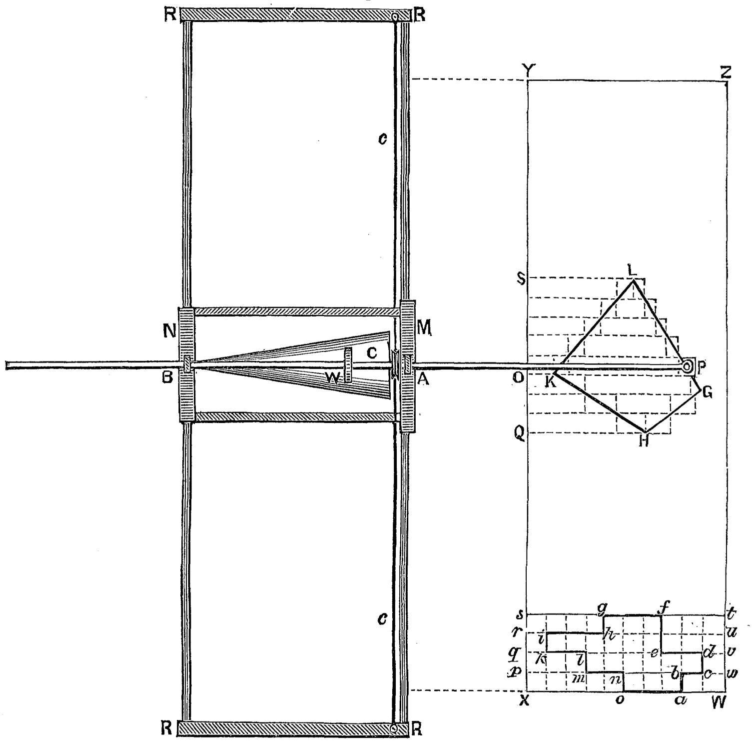
An expeditious mode of ascertaining the area of irregular plane figures is for many purposes of great utility. Apart from the obvious advantages of such a method as applied to the measurement of plots of ground in surveying, its uses to the mechanical engineer in determining the amount of work performed by a machine by means of dynamometrical curves, and the tracings of the indicators attached to steam cylinders, in which the contours of the figures to be measured are irregularly variable, is very great. A planimeter was invented more than thirty years ago by Oppikoffer, of Berne, which in theory seemed to fulfill every desirable requisition, and which was reccommended to its employés by the administration of the public surveys in France. Its expensiveness and the practical difficulties found to attend its use prevented its general adoption; but it continues still to be to some extent employed by mechanical engineers. A simpler instrument, and one much less costly, was exhibited in the Swiss section of the Exposition, by Mr. Amsler-Laffon, of Schaffhouse. The theory of this instrument will be better understood after a brief explanation of the planimeter of Oppikoffer.

OPPIKOFFER'S PLANIMETER.

In the annexed figures, of which the first is a plan and the second a lateral view, are embraced the essential parts of this instrument. These are, first, a cone C, mounted on a movable carriage, M N, with the axis inclined in such a manner as to bring one side into a horizontal position. A rod X Y, parallel to this side of the cone, slides in the direction of its length through supports A B attached to the carriage. This rod is rectangular, or otherwise formed so as to be incapable of turning on its axis. At one extremity it carries a point, or tracer, P, which, in the use of the instrument, is employed to follow the perimeter of the figure the contents of which it may be desired to ascertain. Upon the rod is fixed a small wheel or roller W, convex upon its circumference, which turns freely upon the rod by frictional contact with the cone C. The axis of the cone, between its base and the bearing, carries a small pulley,

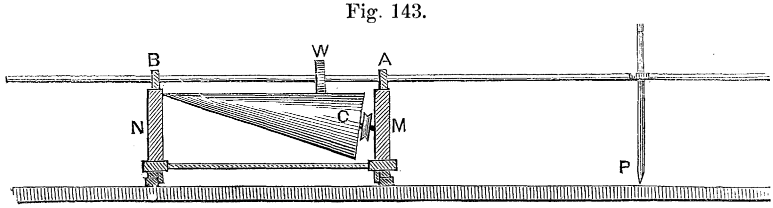
around which passes a stretched cord, *c*, extending from end to end of the framework, or railway, R R, upon which the carriage traverses. By the movement of the carriage the cone is thus made to revolve, and

Fig. 142.



Vertical view.

Fig. 143.



Oppikoffer's Planimeter—end view.

its motion of revolution is transferred to the wheel W. A rack and pinion might evidently be substituted for this cord. In the machine as complete there is a mechanical register connected with the small wheel W, and with the sliding-rod, which records the revolutions made by the wheel when the instrument is in use. The construction is therefore considerably less simple than it is here represented. The carriage runs on rollers on the ways R R, as it is moved by the hand of the operator.

It is obvious that, for the same movement of the carriage, the rapidity of revolution of the wheel W will be variable, according as it is nearer

the summit or the base of the cone. If the sliding-rod be pushed in the direction A B, until the wheel W reaches the vertex of the cone, the wheel will cease to revolve altogether, although the movement of the car may still be continued. Supposing it to be in this position, and the point P consequently at O, the tracer may pass along the line X Y, through the whole range of the instrument, without making any record. By sliding the rod in the opposite direction so as to bring the tracer to the line W Z, and the wheel to the base of the cone, the roller in the course of its movement from W to Z, will make its largest possible record. During this progress the rod will sweep over all the area W X Y Z; and if this area be supposed to contain a certain number of square inches, two hundred for example, and the count of the register should be so adjusted as to read two hundred units at the end of the movement, (the original reading having been zero,) it will be seen that the record will truly exhibit the area passed over. Of course, if the movement had been arrested half-way between W and Z, the record would have been but one hundred, and the area passed over only one-half of that before supposed. Again, if returning to the line W X, and seeing that the index is once more truly at zero, the tracer is moved along the line W X, half-way to X, this motion will cause no change in the position of the roller, because it takes place perpendicularly to its plane, but the roller will be transferred to a point on the cone half-way between the base and the apex, where the circumference is only half what it is at the base. In making then anew the movement from the line W X to the line Y Z, the roller will make but half as many revolutions as before, and the register will record but one hundred units. In the mean time, also, the rod will have swept over only half the area of the rectangle W X Y Z. What is true of these particular cases will obviously be true of every case. In moving in the direction from W X toward Y Z, the register will always truly record the amount of surface swept over. Suppose the irregular but rectilinear and rectangular figure *a b c d e f i k l m n o* to be placed before the instrument for measurement in the position represented. Let the tracer be at *a* and the index at zero. In carrying the point P along the line *a b*, the area *a b p* X is swept over, and its value recorded. If then the tracer be carried along the line *b c*, no record will be made, because the movement is at right angles to the plane of the roller. In this movement, moreover, no new area is swept over. In moving from *c* to *d*, the additional rectangle *c d q p* is covered by the rod, and a corresponding addition is made to the record. From *d* to *e* there is no area and no record. From *e* to *f*, the area *e f s q* is described, and its amount is added to the previous sum. We shall thus have measured the whole area, *a b c d e f s* X. Passing now to *g*, which will not change the reading of the register, we return from *g* to *h*. The rod passes over the area *g h r s*; but as this movement is in a contrary direction to the former, the roller turns backward, and thus subtracts from the total previously obtained the value of this small rectangle. We proceed then from *h* to *i* without

a record, and from i to k subtracting the rectangle $i\ k\ q\ r$. In like manner we subtract $l\ m\ p\ q$ and $n\ o$ X p, and finally return along the line $o\ a$ to the starting point, with a final reading of the register which is equal to $a\ b\ c\ d\ e\ f\ s$ X, diminished by $g\ h\ i\ k\ l\ m\ n\ o$ X s; or to the given figure $a\ b\ c\ d\ e\ f\ g\ h\ i\ k\ l\ m\ n\ o$.

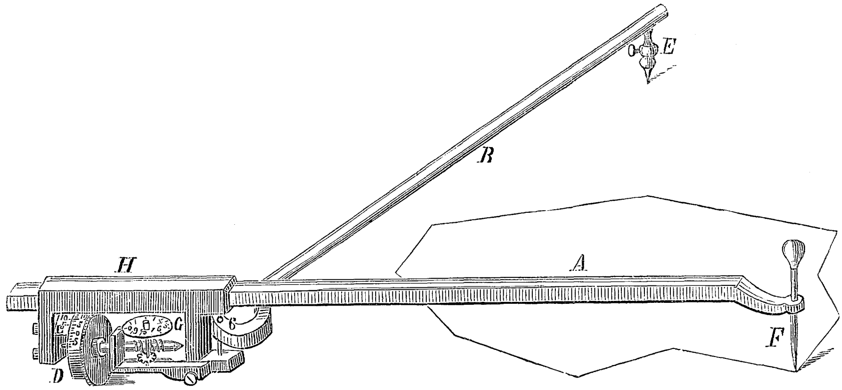
Take next the rectilinear figure G H K L, of which the sides are not parallel to those of the rectangle W X Y Z. We may describe upon it a series of rectangles as shown, of which the sides shall be so parallel; and these may be so described that their salient angles may touch the sides of the figure internally, or so that the re-entering angles of the group may meet the same lines externally. The differences of the first set of these small rectangles, measured as above, will be less than the area of the figure, and those of the second set greater; but the excesses or deficiencies will be so much the less considerable as the rectangles are made more numerous, and are severally smaller, while the instrument will measure every system with equal accuracy, whatever be the dimensions of its elementary parts. Supposing the breadth of these rectangles to be infinitely diminished, their angles disappear, and the tracer, in measuring them, follows the sides of the given figure G H K L. Such is the theory of this very ingenious instrument. In the actual construction, the circumference of the base of the cone is made equal to the generating line of the convex surface. Accordingly, when the wheel W is one inch from the vertex, it makes one complete revolution for every inch which the tracer P moves in the direction X Y. But this is not an essential condition. If a square inch is the assumed unit of surface, all that is necessary to the correctness of the record is, that when the tracer K is one inch advanced beyond the line X Y, as for instance at O, the register shall record one unit for every inch of movement in the direction from X toward Y.

AMSLER'S PLANIMETER.

From what precedes, the theory of the planimeter of Amsler will be easily intelligible. The instrument is shown in perspective in Fig. 144. The arm A slides in the socket H, and may be adjusted to such length as best suits the work in hand. It carries on the side or top certain marks or graduations, with numbers annexed, expressive of the value of certain constants, to be used as will presently be described, in deducing the final results. Each length given to the arm A requires a different constant. The socket H has beneath it the apparatus for registration, which consists, first, of a roller, graduated on its circumference, and provided in the prolongation of its axis with a screw-thread, which acts upon the small horizontal graduated disk G, by means of a pinion. The entire revolutions of the roller are recorded by this disk; an index on the left serving to mark the divisions as they pass. The reading of fractional parts of a revolution is made by means of a vernier, shown at L. A horizontal rod B is hinged to the apparatus just described, and

is fixed to the table, when the instrument is in use, by means of a point, E, at its extremity. At F is a tracer, which, as in Oppikoffer's plan-

Fig. 144.



Amsler's Planimeter.

imeter, is carried along the lines of the figure to be measured. The instrument rests, therefore, on the roller D, and the revolution of this roller is produced by friction upon the paper. The point E being fixed, and all other parts of the instrument free, the movement is necessarily circular; and on this account the instrument is sometimes called the polar planimeter. If we suppose the joint connecting the two rods at C to be inflexible, and the tracer F to be carried round E as a center, it will be perceived that the moving point will describe a circular arc, of which the line joining E F is the radius. This moving radius E F will sweep over a sector, of which the arc is the base, and the radii in the initial and final positions the lateral boundaries. In the mean time the roller D will turn by friction on the paper, and the geometrical fact upon which the usefulness of the instrument depends, is that the extent of the arc developed by the roller is a simple function of the area of the sector swept over.

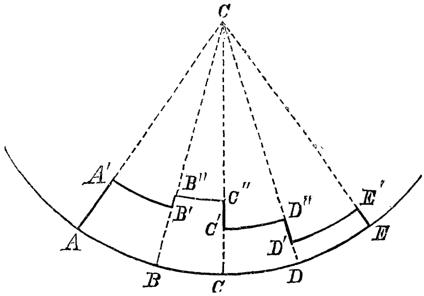


Fig. 115.

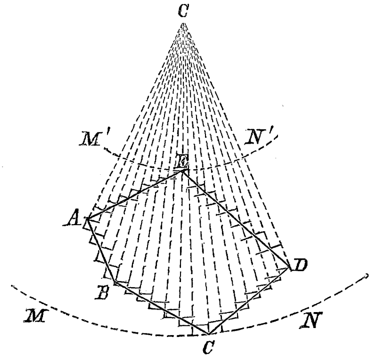


Fig. 146.

The theory of this instrument therefore supposes that every plane figure submitted to measurement is made up of infinitely small circu-

lar sectors, or of the differences of such sectors, precisely as Oppikoffer's planimeter supposes the resolution of the same surfaces into minute rectangles. In Fig. 145, on page 624, if we can measure the whole sector C A E, in sweeping directly from A to E, and then, returning along E E′, E′ D′, D′ D″, D″ C′, C′ C″, C″ B″, B″ B′, B′ A′, and so to A again, can measure the several sectors C E′ D′, C D″ C′, C C″ B″, and C B′ A′, these areas being subtracted from the former by the instrument itself in the contrary movement, there will evidently remain the irregular area A E E′ D′ D″ C′ C″ B″ B′ A′. Fig. 146 shows the extension of the principle to rectilinear figures, and this may be compared with Fig. 142 of Oppikoffer's planimeter.

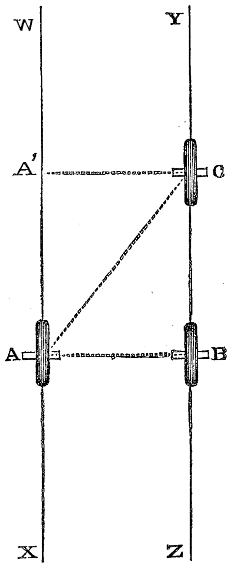


Fig. 147.

It is evident that, in the various movements of the instrument, the roller must, at different times, be differently inclined to the direction in which it is drawn along over the paper. In passing over a given length of track, it will not therefore always develop the same length of arc. It is upon this fact that the truthfulness of the indications depends. Fig. 147 illustrates the relation which subsists between the space passed over and the arc developed. If a roller be moved on a plane surface from A to B, at right angles to its plane, it will slide without turning. If it be then carried forward in the direction of its plane from B to C, being free to roll, it will develop an arc equal to B C. And if it be carried in a straight line, A C, from the initial to the final point of movement, it will both slide and roll, and the arc developed will still be B C. The direction of the plane of the wheel being A A′, and that of the path being A C, the angular inclination between the two will be A′ A C; and if this an-

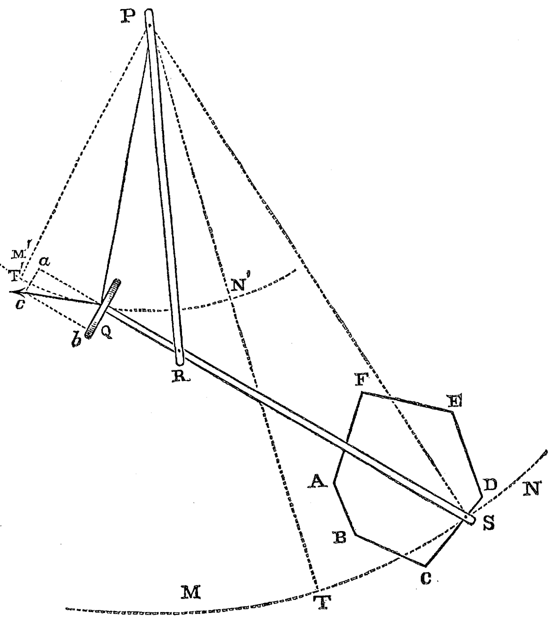


Fig. 148.

gle be represented by φ, the length of path by a, and the arc developed by θ, the relation expressed in the following equation will always subsist, viz:

$$\theta = a \cos \varphi.$$

In order to apply this principle to the operation of the planimeter, we refer to Fig. 148, in which P represents the fixed pole; Q the roller; R the point of union of the arms; and S the tracer. Supposing the joint to be inflexible, and the instrument to revolve about P, the tracer will describe the arc MN, and the roller the arc M′N′. Simultaneously the two small sectors, PST and PQT′, may be supposed to be swept over by the radii, PS, PQ. Put θ to represent the arc developed by the roller; θ' the arc QT′ actually moved over; and θ'' the arc ST described by the tracer. Put also φ = the angle of the plane of the roller to the tangent Qc, that is, to $bQc = PQa$; and ψ = the angle PRQ. Then, as above—

$$\theta = \theta' \cos \varphi; \text{ or } \theta' = \frac{\theta}{\cos \varphi}. \qquad (1.)$$

If now we put $PR = a$; $RS = b$; $RQ = c$; $PS = \rho$; and $PQ = r$; and take S to represent the area of the sector PST, we shall have

$$S = \tfrac{1}{2} \rho\, \theta''; \quad \theta'' = \frac{\rho}{r} \theta'. \quad \therefore \quad S = \frac{\rho^2 \theta'}{2r}.$$

$$\text{And finally (1.) } S = \frac{\rho^2 \theta}{2r \cos \varphi}. \qquad (2.)$$

In the triangle PSR,

$$\rho^2 = a^2 + b^2 + 2ab \cos \psi.$$

But it is evident from the figure that

$$a \cos \psi = r \cos \varphi + c.$$

$$\text{Whence } \rho^2 = a^2 + b^2 + 2bc + 2br \cos \varphi.$$

And substituting in (2.)

$$S = \frac{(a^2 + b^2 + 2bc + 2br \cos \varphi)\, \theta}{2r \cos \varphi} = \frac{(a^2 + b^2 + 2bc)\, \theta}{2r \cos \varphi} + b\theta.$$

In the first term of this value, substitute the value of $\theta = \theta' \cos \varphi$, and there results—

$$S = \tfrac{1}{2}(a^2 + b^2 + 2bc) \frac{\theta'}{r} + b\theta.$$

But $\frac{\theta'}{r}$, or the arc divided by its radius, is the angular movement, or the similar arc corresponding to radius=1; which, if we put $= \omega$, we shall have finally, for the value of the sector,

$$S = \tfrac{1}{2}(a^2 + b^2 + 2bc)\, \omega + b\theta.$$

The angle ω is independent of the position of the roller, and its coefficient is made up of constants; whence the area of the sector PST is measured by the product of the length of the arm RS into the arc developed by the roller, together with a constant multiplied into the angular measure of the sector.

The constant in the above expression will be seen to be equal to the value which belongs to PS in the position represented in Fig. 149, where Q is a right angle. Represent this radius by R, and we shall see that $\frac{1}{2}R\omega$ expresses the area of a sector in a circle W′X′Y′Z′, of which the constant radius is determined by the condition that the plane of the wheel shall be at right angles to the circumference of the circle WXYZ, which is the direction of its movement. While the wheel is in this position it slides without revolving. Hence, for the entire circle W′X′Y′Z′ no record will be made; and if, in the measurement, the tracer is carried entirely round the pole P, it is necessary to add a constant which is equal to this circle in value.

If the figure measured lies wholly on one side of the instrument, as in Fig. 144, the constant occurs in the subtractive part of the movement as well as in the additive; and hence no account need be taken of it.

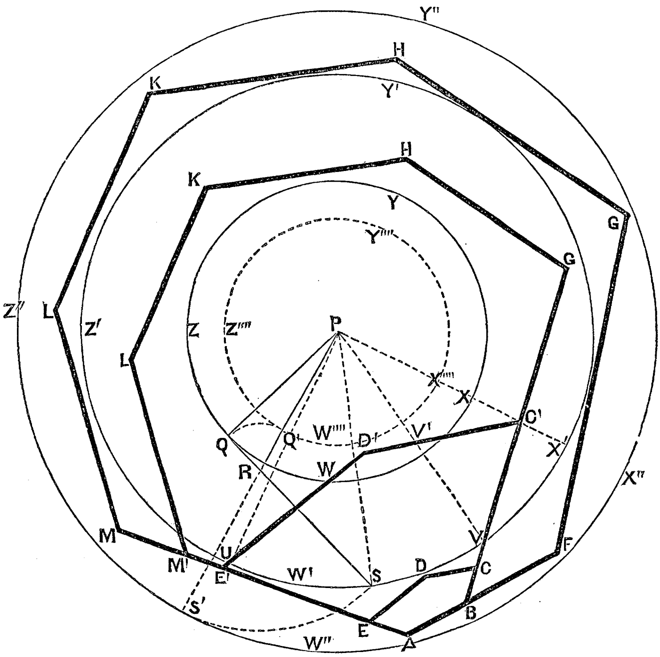


Fig. 149.

The term $b\theta$, which is the variable part of the value of S, measures the portion of the sector PST, Fig. 148, which is between the arc described by the tracer and the circumference of the constant circle only. Taking in Fig. 149, PS′ equal to PR+RS, and sweeping with the tracer around an entire circumference, $b\theta$ ought therefore to be equal to the ring contained between the two circumferences W′X′Y′Z′ and W″X″Y″Z″. This ring equals

$$\pi(PS'^2 - PS^2) = \pi\Big((a+b)^2 - (a^2+b^2+2bc)\Big) = \pi\Big(2(a-c)b\Big).$$

In the position supposed, PR and RS being in a straight line, the plane of the roller coincides with the plane of its motion, $\varphi = 0^\circ$, $\cos\varphi = 1$, and $\theta = \theta'$.

Hence, in the entire revolution, Q′ taking the place of Q,

$$b\theta = b(\text{circumf. } W''''X''''Y''''Z'''') = b(\text{circ. to rad. } (a-c) = \pi\left(2(a-c)b\right).$$

Which being equal to the area of the ring as just found, confirms the conclusion above deduced.

When a figure lies entirely within the ring just mentioned, as ABCDE, the additive part of the record is made while moving along the outer lines from E to A, from A to B, and from B to C: the subtractive part while returning from C to D and from D to E.[1] But if we suppose this figure enlarged so that its sides BC, AE, cross the circumference W′X′Y′Z′, the roller which is turning in the positive direction while the tracer moves along BC, ceases momentarily at V to revolve, and then from V to C′ turns in the contrary, or negative direction. But it is now measuring the space VC′X′ which is external to the figure, lying between it and the fixed circle W′X′Y′Z′, and which ought to be subtracted; while in the subsequent movement from C′ to V′ the entire space C′X′VV′ is added to the positive record, and the difference of the two is the part VV′C′ of the figure. Thus the areas expressed by $b\theta$ are always referred to the circumference of the fixed circle W′X′Y′Z′ as a base, whether the line described by the tracer is within or without this circle.

From this consideration it results that when the pole of the instrument is in the interior of the figure, as at P, Fig. 149, and the sides of the figure are wholly exterior to the circumference of the fixed circle W′X′Y′Z′, the record of the register is the sum total of all that part of the figure which is between the said circumference and the perimeter, and is wholly positive. But when any part of the perimeter lies within the fixed circle, so much of the record is negative as relates to the spaces between such portions of the perimeter and the circumference. If the negative areas exceed the positive, the final record will be negative. It is therefore best to set the register at the number denoting the value of the constant circle before beginning the measurement; since, so long as the figure has *any* magnitude, the negative areas cannot exhaust this entire constant. In Fig. 149, ABG′H′K′L′M′ is an area in which this expedient would evidently be necessary in order to secure a positive result. But there are often cases in which it may be doubtful what would be the sign of the result without the addition; hence it is better always to make it.[2]

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[1] As the instrument is ordinarily graduated, the record diminishes in moving from right to left. With such a graduation it is necessary to pass over the sides of the plot in an order the reverse of that stated in the text; *i. e.*, from E through D, C, B, and A to E again.

[2] The demonstration of the theory of the Amsler planimeter given in the text is the same in principle, though not in form, with that given by Messrs. Piccard and Cuenoud. The result may be reached more briefly by finding directly an expression for the area of the ring

In the construction of the instrument it is desirable to proportion its several parts in such a manner that the rectangle of the arm b into the entire circumference of the roller may be some convenient unit of surface, or a definite number of such units. The number of revolutions, or of revolutions and fractions, recorded by the register, will then be either directly the expression of the area sought, or easily convertible into such an expression. For different lengths of the arm the values will be proportioned to the length. Hence it is easy to make them such as to facilitate calculation, 1, 2, 5, 10, for instance. For each length of the arm b a new value must be computed for the constant circle, and this will not necessarily be a round number; but as it is merely additive, its form is unimportant.

This planimeter from its simplicity and its cheapness seems to be destined to come into more extensive use than that of Oppikoffer. Its price is only from 50 to 80 francs; while that of the instrument of Oppikoffer is from five to six hundred. There is a possibility of error in its indications, as there must always be in instruments in which friction is relied on for the transmission of motion; but it is so easy to make repeated measurements, and each measurement requires so little time, that no serious error is likely to vitiate the ultimate determination.

III.—MECHANICAL CALCULATION.

At first thought nothing seems more paradoxical than to propose to perform operations in arithmetic by machinery. To most persons the process of calculation involves a species of mental labor which is painful and irksome in the highest degree; and to such, no part of their educational experience recalls recollections of severer trials, or of burdens more difficult to bear. That this toil of the pure intelligence—for such it certainly seems to be—can possibly be performed by an unconscious machine, is a proposition which is received with incredulity; and even when visibly demonstrated to be true, is a phenomenon which is witnessed with unmingled astonishment. And yet all of us have been more or less in the habit of employing artificial helps to calculation all our lives. The same thing has been done by all races of men, and in all ages, even before the dawn of civilization.

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lying between the circumference of the circle, called above the *fixed circle*, and that corresponding to any value of the variable radius ρ. Putting A for the area of this annulus, and employing the notation given above, we shall have—

$$A = \pi (\rho^2 - R^2)$$

And as we have found $\rho^2 = a^2 + b^2 + 2bc + 2br \cos \phi$,

And $R^2 = a^2 + b^2 + 2bc$,

It follows that $A = 2\pi br \cos \phi$

Now $2\pi r$ is the circumference traced at the same time by Q, the roller; and if θ represent the arc developed by the roller in the same time, it follows (pp. 625, 626, Fig. 147,) that—

$$\theta = 2\pi r \cos \phi.$$

Hence $A = b\theta$, as above. This proposition, though here applied to the case of an entire revolution, is equally applicable to any arc ω, less than π.

The word *calculation* itself recalls the *calculi*, the pebbles, which, next to the fingers of the human hand, formed the earliest, as they were the simplest, of all calculating machines. Nor should we forget that, laborious as are numerical operations generally, and intolerably wearisome as we find them when they are greatly protracted, they are the mere sport of children compared with what they would have been without the aid of an artificial system of numeration, like that which is provided in the Arabic numeral characters. Our system of numeration, if not a machine, is a machinery; and without it, or without something substantially equivalent to it, every numerical problem involving more than a very limited number of units would be totally beyond the grasp of the human mind.

Machines for simply *counting* are common and familiar. We see them constantly in use for numbering railroad tickets, bank-notes, and other similar objects, and they are attached to steam-engines to record the number of revolutions made during a day or during a vogage; or to gas-meters to keep account of the volume that has been consumed during a determinate time. None of these things excite surprise. There is no mystery in the fact that a machine can be made to count, though in the case of the class of instruments last named it sometimes appears to customers very mysterious that they can be made to count so much.

But in the counting machine is involved the essential principle of all machines for calculation. It is obvious that the machine which will count single units may be be made to count *twos*, *threes*, *tens*, *fifties*, just as well. The necessary modifications are matters only of mechanical detail. But this process is multiplication; so that, except for the increased number of parts, a multiplying machine is only a counting machine in a new form. Division is multiplication reversed; and when the direct process is possible the reverse follows as matter of course.

The ordinary counting machine adds at each operation a single unit to the previously accumulated sum. A multiplying machine, such as we have just supposed, may add to the preceding sum the whole of a given multiplicand, though consisting of many units, at every successive movement. But in order to adapt such a machine to the varying uses of the arithmetician the construction must be such as to allow the operator to alter the multiplicand at his pleasure. Granting that this end has been secured, then any product of any two numbers may be obtained with no further trouble on the part of the person using the machine than that of setting and turning it. Or if we suppose the machine to be driven by a mechanical motor, then the only attention which it will be necessary to give to it will be, first, to set the markers of the scale to the multiplicand, and secondly, to place a stop for the purpose of arresting the movement when the multiplier has been exhausted. When the machine stops the product will appear.

Machine addition is more troublesome than machine multiplication, because it requires the attendant to re-set the markers after each suc-

cessive movement. There seems to be no getting over this difficulty, and no reducing of simplicity lower. Though the machine will fulfill perfectly the function of a mechanical memory, the mind must dictate in the first instance what it is to remember.

Subtraction being only the reverse of addition, it is provided for when addition is made possible; and thus it is seen how, without invoking any other principle, mental or mechanical, than is already familiar to all the world, it is quite possible to construct a machine to perform all the operations of ordinary arithmetic.

And yet, while in the theory of the calculating machine there is nothing which is not sufficiently simple, in the practical solution of the mechanical problem which it involves there are one or two points of difficulty which have constituted the despair of many inventors, and with which very few have succeeded in dealing successfully. The first of these is to secure such a construction as shall admit, without troublesome complication, of the setting of the machine, as above appears to be necessary, to the numbers presented in the original problem; and the next, to provide a simple expedient for carrying forward the tens found in the result of the addition of each order of figures to the order next higher. To these matters we shall presently return.

Since the dawn of mathematical science in Europe the attempt to construct a machine capable of satisfactorily performing arithmetical operations has occupied the attention of a great number of ingenious men, several of whom have been among the most celebrated of their time for originality of genius, and for the large contributions which they have made to the progress of science. Notwithstanding the force of intellect and the varied ability which, for some centuries, was thus concentrated upon this problem, the history of the labors of most of these inventors amounts to little more than a history of successive failures; and it is only within recent years that a really serviceable calculating machine has been at last perfected. The most successful machine of this class which modern ingenuity has produced—putting aside for the moment the "difference engines," such as those of Babbage and Scheutz—is probably the "arithmometer" of Mr. Thomas de Colmar, which was exhibited in the French section of the Exposition, where it was constantly the center of a curious crowd.

In a lively little book, by Mr. Jacomy Regnier, prepared in the interest of this inventor, is contained a series of brief notices of those who had attempted earlier to walk in this difficult path. The earliest named belongs to the tenth century, and was no less considerable a person than Gerbert, archbishop of Rheims and chancellor of France, who finally became pope, under the name of Silvester II, but who, in early life, was an obscure shepherd in the mountains of Auvergne. Even while in this humble condition his inventive genius displayed itself in several striking modes. He constructed a hydraulic organ, of which the tubes were formed of bark skillfully detached unbroken from the branches of trees,

while the blast was produced by the action of falling water. Finding it difficult to divide his day when his time-piece, the sun, was obscured by clouds, he constructed with his pocket-knife a clock, which measured very tolerably the hours, and which was the germ of an elaborate and artistic achievement of the same kind in later years at Magdeburg. This singularly ingenious peasant attracted the attention of an intelligent ecclesiastic, Geraud de Saint Ceré, prior of the Benedictine monastery at Aurillac, who received him into his religious family, made him a monk, and sent him to the Moorish universities—then the most renowned in the world—of Cordova and Seville. A residence in those cities was at that time prohibited to Christians; but Gerbert quietly took the habit of a Mussulman, followed diligently the course of studies in both universities, and returned to Barcelona in the year 968, thoroughly skilled in the learning of the Arabian doctors, and the bearer of the most valuable gift which the West had yet received from the East, the Arabic numerals.

Possessed of this powerful instrument of calculation, Gerbert was seized with an irrepressible desire to enlarge the value of the gift by relieving the possessor of the drudgery attendant on its use. He knew, it is asserted, that the Arabians had attempted the same thing before him, and that they had all failed; but this knowledge served only as a stimulus to his zeal. His impatience to embody his conceptions into form led him, during a residence in Rome, to apprentice himself to the trade of a turner. It was his conviction that so soon as he should be able to construct and to combine with his own hands the elements of his various devices, he could not fail to secure an early and an easy success. Unhappily his hopes were disappointed. The ingenuity which had triumphed over so many difficulties before was compelled to confess itself at last baffled. He constructed many calculating machines. They had all one common fault—they would not calculate.

Albertus Magnus, ecclesiastic, teacher, master of the sacred palace, archbishop of Ratisbon, and finally, by preference, simple monk, was distinguished for his vast acquirements and for his restless scrutiny into the mysteries of nature. His zeal in the prosecution of an endless variety of objects, some of them no doubt substantial, but many of them visionary; his knowledge, out of harmony with the dense ignorance of his age; and the numerous curious experiments and wonderful discoveries which marked the progress of his researches, won for him among his superstitious contemporaries the character of a sorcerer. He constructed a human head of brass, which was reputed to have the power of responding to interrogatories; and it was affirmed of him that he was accustomed to consult this head as an oracle in the prosecution of his investigations. The sequel of the tale is eminently characteristic of the age to which tradition assigns it. Such an abominable contrivance could not fail to be regarded as an outrage upon the feelings of all right-minded persons, too shocking to be patiently endured; and hence it occasions

us no surprise to be informed that a blow from the indignant staff of the "angelic doctor," Thomas Aquinas, himself a pupil of Albert, brought sudden and deserved destructionu pon this monstrous monument of impiety.

The imaginative author above referred to, Mr. Regnier, asserts, upon what authority it is difficult to say, that this head was nothing else but a calculating machine, and that the responses which it rendered were not sentences audibly uttered, but were merely the results of computations presented in visible characters between its lips.

The famous Roger Bacon, a contemporary of Albert, laboring like him also under the disadvantage of a reputation equally equivocal, constructed likewise a head, possessing, as it was supposed, the same marvelous endowment. The story of Friar Bacon's brazen head, and of the ruin which befell at once the invention and the hopes of the inventor, is among the most familiar of the legends which have come down to us from the thirteenth century. This, too, according to Mr. Regnier, was a machine which answered only to arithmetical questions, and which was constructed in a form so fanciful merely for the sake of impressing the spectators of its performance with the profounder astonishment.

To descend to later times, the first form of apparatus, of which we have any authentic account, designed to facilitate, by mechanical means, the operations of arithmetic, is found in what are called the rods of Napier. The name of Napier, baron of Merchiston, is associated with some of the most useful inventions which have marked the progress of mathematical science. Among these may be mentioned the system of logarithms, and the simplification of spherical trigonometry by the introduction of the well-known "analogies" and "circular parts." Lord Napier's contrivance for facilitating arithmetical computations, applied only to multiplication, and consisted of a set of rectangular rods, sometimes called "Napier's bones" from the material of which they were constructed, divided into squares or cells, nine in number upon each rod, in which were written the products of the several digits in their order as they stand in the common Pythagorean table. Fig. 150 represents one of these rods, embracing the number and its several products by the nine digits taken successively. Each cell is divided by a diagonal line running downward from right to left. The original number itself, and the product, if it contains but a single digit, is written in the right-hand triangle thus formed. When there are two digits in the product, the unit's figure is written in the right-hand triangle, and the ten's figure in the left. When a number consisting of several figures is to be multiplied, a series of rods must be selected which carry these figures severally in their uppermost cells, and arranged side by side, as in Fig. 151, so as to present the

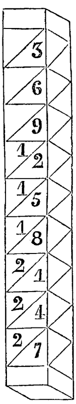


Fig 150.

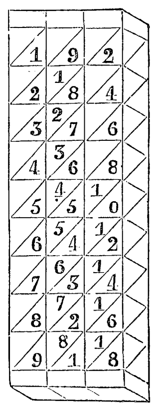


Fig. 151.

multiplicand complete in reading directly across. The product of this multiplicand by any digit will then be found in the row of cells corresponding to the multiplier; remembering that, in reading, the sums of the figures are to be taken which stand in the successive diagonal cells.

It will be seen that the product of the multiplicand can only be taken by one digit at a time. The successive partial products, when the multiplier contains several figures, must be written down and added according to the ordinary rules for multiplication in arithmetic.

Though this contrivance is ingenious, it constitutes but a short step on the way to a calculating machine. The loss of time inevitable in the selection and arrangement of a suitable set of rods for any multiplication is too serious a disadvantage to allow the system to become practically useful. Many inventors diligently strove to remove this objection by attaching the columns of cells to cylinders, or to polygonal blocks of wood, capable of turning on their axes. One of these, Petit, employed at length but a single cylinder, with sliding columns, which could be pushed out of the general group, so as to present the proper combination detached from the rest. But all these expedients were unsatisfactory, as it is evident that they must have been, since one important condition of the usefulness of the system is that the columns in use shall be as nearly as possible in juxtaposition.

The contrivance of Petit excited the interest of a man since very famous in the scientific and literary history of France, the man to whom in our own time we have seen imputed, however absurdly, the merit of the greatest of the discoveries of Newton—Blaise Pascal. Finding himself unable to improve upon the invention of Petit for perfecting the usefulness of the Napierian rods, Pascal conceived the bolder project of constructing a machine which should truly calculate. He succeeded in a manner which was not a success; for his machine was formidably complicated, and the range of its capabilities was exceedingly limited. And yet, remarks the historian, of all the creations of this great man, there was none on which he more persistently wearied his genius, more unprofitably wasted his hours, or it may even be said, more rapidly wore out his life, than on this.

Imperfect as was the machine of Pascal, it was regarded as a marvelous conception, and it won for its author universal applause. Many ingenious artisans directed their efforts toward its improvement; among them, Grillet, horologer to Louis XIV. This accomplished mechanician succeeded to an important extent in simplifying the machinery of Pascal, and in reducing the construction to a form in which it might have been of practical utility had not its performance been limited to a very few places of figures. The author of this improvement made a secret of its mechanism, but exhibited it to the public for a fee. Its construction remains still unknown, and would have no present interest but for its relation to a little episode in the life of a much greater man than Grillet,

one of the greatest whom modern Europe has produced, the celebrated Leibnitz.

Conti, himself a distinguished mathematician, said of Leibnitz, "He aimed to surpass all mathematicians. There is hardly a purpose of civilized life for which he did not invent some machine; but none of his machines succeeded." The applause with which all Europe rung over the achievement of Pascal, which was regarded as a triumph of genius wholly without a parallel, fell painfully on the ear of Leibnitz. He was now in the very zenith of a glory which few men by the mere force of intellect have ever attained. The Emperor of Germany, the Czar of Russia, the Elector of Brandenburg, all the German princes, had lavished upon him dignities, pensions, honors; all the academies of Europe enrolled him with eagerness on the list of their associates; apparently there remained for him no scientific distinction further to attain; and yet, in the midst of all his honors, the gifted, favored, courted Leibnitz was not happy. The machine of Pascal troubled his slumbers. He resolved to create a new one which should throw that marvelous achievement into eclipse. This single project presently absorbed all his thoughts. Philosophy, chemistry, physics, mathematics, correspondence with the learned, relations with monarchs, everything he put aside that he might gather all his forces, and give his whole genius and his whole time to the service of this new ambition. For nearly four years he lived only for this one single end, to construct a calculating machine superior to that of Pascal. After having in some part perfected his device he sent the plans of it to the Royal Society of London; and at a later period he laid them before the Academy of Sciences of Paris. According to these plans, the machine was designed to execute the four fundamental operations of arithmetic. He had expended on its construction a sum of one hundred thousand francs; and yet the machine was found after all to be poorly executed, uncertain in its operation, and incapable of performing an addition or subtraction extending beyond four figures. To complete his discomfiture, it began to be hinted, at first in timid whispers, and afterward in open and bold assertion, that the machine which had cost Leibnitz so much of his time and labor and money, was neither more nor less than an imitation, almost servile, of the contrivance of Grillet, a machine which had some time previously remarkably disappeared, having been disposed of by its inventor, no one knew how. The mechanical construction of this instrument was, as we have seen, never made publicly known. Whether Leibnitz, as was maintained and believed, had really become its secret purchaser, and whether, in despair of originating anything better himself, he had finally determined to adopt it as his own, is a question which cannot, of course, now be ever satisfactorily settled; but one thing which is matter of history is the fact, that the machine of Leibnitz, for practical utility, was inferior to that from which he was asserted to have copied.

The logarithmic scale of Edmund Gunter, first constructed in 1624,

may be classed among the instruments designed to facilitate calculation by mechanical means. The divisions of this scale correspond to the numerical values of the logarithms of numbers. It reduces the operations of multiplication, division, and the extraction of roots, to the addition and subtraction of lines. In theory, its powers are very great; in practice they are comparatively limited, from the fact that the divisions must either be very small, or the dimensions of the instrument itself be too great for convenience. In its original form, an additional source of inaccuracy and loss of time was found in the necessity of employing a dividing compass in using it; but this disadvantage was removed in the modification introduced by Leadbetter in 1750, and afterwards attributed to Jones, in which were embraced two rules sliding side by side. A further improvement, made by Leblond, in 1795, and Gattey, in 1798, consisted in giving to the sliding rules the form of concentric circles. The circular form possesses the advantage of admitting a greater length of scale conveniently within the reach of the operator; but still, without greatly exceeding the dimensions to which, for any practically useful purpose, such a machine must be limited, it is impossible to secure results which can be relied on beyond three places of figures.

To the list of those who from time to time attempted the construction of calculating machines, properly so called, must be added the names of Sir Samuel Moreland, (1773;) Perrault, architect of the Louvre and of the Observatory of Paris, (1699;) the Marquis Poleni, famous for his masterly achievement of securing St. Peter's from ruin, after all other architects had pronounced the case hopeless, (1709;) Leupold, member of the Berlin Academy, (1727;) Clairault, illustrious French geometer, a member of the Academy of Sciences at eighteen years of age, (1750;) Lépine, distinguished horologist of Paris, (1725;) Boissendeau, (1730;) Gersten, (1735;) Pereire, (1750;) Diderot, (1760;) Rowning, (1770;) Lord Stanhope, (1776;) Matthew Hann, (1777;) Müller, (1784;) Abraham Stern, distinguished mathematician of Warsaw, (1814,) and probably many others. Of the effort of Diderot, Mr. Regnier, to whom we are indebted for much of the foregoing information, amusingly says: "Since the arithmetical machine, called Diderot's, has been described at length in the great Encyclopedia, we will say nothing about it here, but will content ourselves with recalling the fact that nearly all the *savants* of the Encyclopedia are reputed to-day to have contributed, with all their science and all their genius, to the creation of this clumsy affair, of which the memory of Diderot alone has long borne the responsibility."

In the year 1822, a French inventor, Mr. Thomas (de Colmar,) patented an invention, in which the problem of the calculating machine was first satisfactorily solved. This statement is not in conflict with the fact, which is not forgotten, that, in 1821, Mr. Babbage, of London, commenced the construction, under the patronage of the British government, of the famous difference engine, of which the original promise

was so great, but which has never been completed. The imperfect condition in which that remarkable machine has been left, is a consequence not of any fault in its design, but of the discontinuance by the government of the appropriations necessary for the continuance of the work. Mr. Babbage's machine was not intended to perform the ordinary operations of arithmetic, and hence it is not in place to consider it here.

Since the expiration of the patent of Mr. Thomas, many projects for machines of this description have been patented in Europe. It would be difficult at present to form a complete list of the inventors who have busied themselves with this fascinating problem. What is remarkable about them, however, is that the most are only known as projects, none of them having been successful in securing that kind of evidence of approbation from those who need such help which is furnished by their adoption in use; while, of the few that have been received with the greatest favor, all have borrowed, more or less directly, the distinctive characteristic of the machine of Mr. Thomas.

In the official general catalogue of the Exposition of 1867 there were enrolled the names of a number of exhibitors of calculating machines. Only two machines of this class, however, actually presented themselves. One of these was exhibited by Mr. Oprandino Musina, of Mondovi, Italy, and was called by him a "pocket machine" for addition and multiplication. It was very small and exceedingly simple, being in the form of a rectangular solid, eight inches long and an inch square in cross-section. Looking upon the top there are perceived a row of apertures, through each of which may be seen a single figure. These figures are inscribed upon the outer circumferences of as many small wheels or drums concealed in the box, which have their faces in the same vertical plane, and their axes horizontal and at right angles to the sides of the box. Upon the vertical side, toward the observer, there is an equal number of fixed dials, which carry a series of numbers, from 0 at the top to 9; the whole circumference being divided into ten equal parts. A little index, like the hour-hand of a clock, on each dial, points, when the instrument is at rest, to the zero. Its position is then vertical. A button on this index permits the operator to turn it in the order of the numbers; and as he turns, the corresponding drum in the interior turns also and to the same extent. It will be understood that the figures on the top record the result, while the little cranks, as they may be called, serve to the performance of the operation. The right-hand drum and dial answer to the place of units; the next toward the left, to tens; the next to hundreds, and so on.

Suppose we wish to perform addition; we must first see that no characters appear in the openings at the top except zeros. Let it be required to add 267 to 431. We begin with 431, and turning the units' crank to the first division of the dial of units, the number 1 appears in the opening at top. The crank when released, returns spontaneously to zero, by the recoil of a spiral spring attached to its axis. It will be per-

ceived, of course, that it turns the drum in the interior, by means of a ratchet and catch. The second crank, or crank of tens, is then turned to 3 and released; and the third to 4. The number 431 then appears in full on the top of the box. The other number, 267, is then added in the same way, beginning with 7 in the units' place. Turning the first crank to the figure 7, the drum advances seven divisions, and as it was previously advanced *one*, the final reading will be 8. The next crank is then turned to 6, and the reading of the tens becomes 9. The third crank is turned to 2, and the number of hundreds reads 6. The sum of both numbers is then presented in the openings at top, and will be 698.

In this example there has appeared no necessity for *carrying*. But suppose to this sum, 698, it is proposed to add 875. As we turn the units' crank from 0 toward 5, the number 9 first appears at top, and then the zero. While the crank is moving from 1 to 2, therefore, a unit must be carried from the first drum to the second. This is effected by a ratchet connection between the successive drums, which takes effect only once in each revolution, and when the drum on the right, or, as we may call it, the driving drum, is passing from 9 to 0. In the present instance the units' drum, after passing zero, goes on to 3, 13 being the sum of 8 and 5, and the 1 (ten) having been carried forward to the next drum. But here occurs a necessity for carrying again, since the reading of that drum is already 9. This 9 will accordingly change to 0, and the third drum, which marked 6, will exhibit the number 7. Turning now the second crank to 7, the drum which stood at 0 advances to 7 also. And turning the third crank to 8, the 7 of the third drum becomes successively 8, 9, and 0 (carrying 1,) and afterwards 1, 2, 3, &c. to 5. The total sum is then seen in the openings on the top to be 1,573.

For multiplications, it is evident that each crank must be similarly moved as many times as there are units in the multiplier, before advancing to the next. Since the movement of the crank is possible in only one direction, subtraction and division by means of this machine are impossible. Subtraction may be performed by adding the arithmetical complement of the subtrahend; which, if the machine were otherwise serviceable, would be a partial compensation for the disadvantage. This little contrivance hardly deserves, perhaps, to be called a machine.

The other object of this class mentioned above as having been present in the Exposition was the invention of Mr. Thomas de Colmar, spoken of in the foregoing brief historical sketch. Although this invention, if judged by the date of its patent, is not recent, it is in this country so almost unknown that it has for us the character of an invention entirely new. At the same time the complete solution which it furnishes of a mechanical problem which had baffled the ingenuity of inventors, the rapidity with which it executes its operations, and the facility with which it may be managed, entitle it to something more than a cursory notice.

The *arithmometer* of Mr. Thomas presents, externally, the appearance

of a neatly finished box; the dimensions being determined by the number of places of figures to which it is designed that the operations of the machine shall extend. This number is generally six, seven, or eight for each factor in multiplication, or twice as many in the product; but Mr. Thomas has constructed machines with as many as sixteen figures in the factors, and thirty-two in the products. For a machine of eight places in the factors, the measurement in length is about two feet, the breadth being nearly seven inches, and the depth three and a half. On opening the box, there appears, first, a metal plate having a number of grooves cut through it equal to the number of characters to be admitted into a multiplicand, parallel to each other in direction and at right angles to the length of the box. These grooves are graduated, and the divisions are inscribed with the characters from 0 to 9. An index which slides in each groove can be placed opposite to any division. On the opposite side of the box from the operator, and beyond the grooves, are an equal number of small circular openings, one being opposite to each groove, in which the results of the operations are designed to appear. These results are formed of characters inscribed in a circular arrangement on the plane faces of as many disks which are concealed within the box, but present their successive characters at the openings as they revolve. At one end of the box in the interior is a small crank which turns horizontally, and is the means by which the machine is operated.

In using the machine it must first be seen that no characters are visible in the openings in which the result is to appear. The indexes are then set in their grooves opposite to the characters which form the first number to be used; a single turn is given to the crank, and the same characters appear in the little windows opposite the several grooves. Another arrangement given to the indexes in the case of addition, and another turn given to the crank, add a second number to the first; and this process may be continued as fast as it is in the power of the operator to effect the necessary changes of the indexes. For multiplication the expedition is greater. The multiplicand having been once set by means of the indexes, multiplication by any number is effected by the simple process of turning the crank as many times as there are units in that number. And that nothing may be left dependent on the memory or subjected to the chances of forgetfulness on the part of the operator, there is another series of smaller windows in which appears the record of the number of turns given to the crank, as each successive figure of the multiplier is employed. When the multiplication by the unit's figure is complete, that by the tens follows, and is, by a simple expedient, added to the first. As, in written arithmetic, we begin the tens' product one place to the left, so in this mechanical process we transport the units' product one place to the right—the result being identically the same. In order to allow of this movement, the plate which carries the result, and which is independent of that to which the indexes belong, lifts out of connection with the machinery below, being hinged by a sliding hinge

on its outer edge, which permits it to be moved right or left. This plate having been raised by a button, moved one place toward the right, and readjusted, the multiplication by the ten's figure takes place as before, the number of tens in the multiplier being at the same time recorded in its proper little window. To multiply by the hundreds, thousands, &c., is only to repeat the operation just described for the tens.

So much for the machine as it appears to the spectator; now for the transmission of the motion. Each recording dial above described carries immediately beneath it a beveled pinion, which is geared into another beveled pinion on a horizontal arbor, its own axis being vertical. This horizontal arbor extends from beneath the dial directly across the box, and underneath the groove belonging to that dial with which it is coincident in direction. This arbor is square, or angular, and it carries a pinion which can slide on it from end to end, but cannot turn round without turning the arbor also. And immediately under the pinion is a barrel or cylinder having the same length as the grooves above it, upon the surface of which are projecting teeth or leaves extending longitudinally to unequal distances. On one-half the barrel there are no leaves at all. On the other half, the leaves form a series of nine in all, increasing in length from one-tenth of the length of the cylinder to nine-tenths. It is as if a full-leaved pinion of eighteen or twenty teeth had been originally made, and afterwards cut down, so as to present the limited number of unequal leaves just described. The effect of this construction will now be understood, and the understanding will be facilitated by reference to the little figure here annexed. Here, A represents a long-leaved pinion from which the leaves have been partially cut away; and B represents a spur-wheel gearing into the pinion. It is obvious that if B is near the end A of the large pinion it will be acted on by only a few of the leaves of the pinion, while at the opposite end it will be acted on by them all. There are twenty leaves in the pinion here represented. Only nine of these are needed in the machine of Mr. Thomas, the rest being cut away entirely; and of these nine the lengths increase in the proportions just stated, so that the spur-wheel B, according to the position given it by sliding it on its arbor, may engage during a revolution of A any number of leaves, from one to nine; and may even, also, by being moved beyond the reach of any of the leaves, escape being acted upon by them altogether.

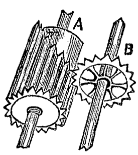


Fig. 152.

It will now be seen what is the effect of sliding the indexes as described above, in the setting of the machine. Each of these indexes commands one of the little spur-wheels, B, and places it at that point in which it will engage as many leaves of the large pinion, A, as there are units on the graduated scale opposite to it. The revolution of A advances the spur-wheel just so many teeth, and this spur-wheel, turning its arbor with it, transmits a movement of precisely the same number of places through the bevel gearing to the dial.

It must now be provided that all the large barrel-pinions shall turn simultaneously. This is effected by means of a horizontal arbor extending longitudinally along the box, and acting on the arbors of all the barrels by means of bevel-gearing. Finally, this longitudinal arbor is similarly driven by a vertical arbor at the right hand extremity of the box; a crank turning horizontally being attached to this vertical arbor. This last complication was unnecessary, since the crank might be attached directly to the end of the horizontal arbor; but the inventor has preferred the construction actually employed, because it permits to inclose the crank in the box without detaching it; and also because of the small altitude (three and a half inches) of the machine.

Thus far nothing has been said of the provision for *carrying for tens.* This is effected by means of a mechanism upon the arbors of the barrels and spur-wheels above spoken of, and between the barrels and the dials, of which the parts are ordinarily out of gear, but which when brought as occasion requires to engage with each other, cause the dial to advance one place, after the advance regularly due to the revolution has been completed. The movement by which the parts are thrown into gear is produced by the action of a pin beneath the dial of the next place to the right, which pin is fixed at such a point as to operate just as the nine of that dial is giving place to zero. But no carrying takes place anywhere along the line until all the leaves of the barrel-pinions have completed their effect; and this (because all those leaves are on one side of the barrels respectively, while the opposite sides are blank) occurs when the revolution is half completed. The carrying, if any is necessary, will then take place in the several orders of figures successively, beginning at the right. The propriety of this arrangement will appear when it is considered that the carrying from a lower order may itself be the occasion necessitating a carrying from the next higher; as was illustrated by the example employed in speaking of the machine of Musina. Moreover, as a little force is necessary in producing the movement required in carrying, it is important that the resistances should not be allowed to accumulate. This is prevented by making the movements consecutive and not simultaneous. In the machine of Musina no such provision has been made, and consequently, when several figures are to be carried at once, as may happen, for example, when a unit is added to such a number as 9999999, the united resistance is sufficient to endanger the strength of a delicate mechanism. This consideration explains why it was thought expedient to confine all the leaves upon the barrel-pinions to one-half the circumference. They thus accomplish their work in the first half of the revolution, and leave time to make all the subsequent movements of carrying consecutive.

We thus see how addition and multiplication are provided for. It remains to consider the cases of subtraction and division. It has been stated that the recording dials are turned by a bevel gearing, the axes of the driving gear-wheels being horizontal, while those of the dials

themselves are vertical. Now when, by a mechanism of this kind, a rotation round a horizontal axis is transmitted to a wheel having its axis vertical, the direction of rotation which this latter wheel will assume will depend on the limb by which it is engaged. If attacked on one side of the center it will turn one way; if on the other side the other way. In the machine under consideration each of the horizontal arbors beneath the dials carries *two* bevel gear-wheels connected together and capable of sliding together on the arbor, but placed so far apart that when one of them engages the pinion of the dial wheel, (which is between them,) the other is thrown out. This whole system of sliding gear-wheels on all the arbors is commanded by a frame-work and lever arrangement, such that, by moving a button, the direction of rotation of all the recording dials may be simultaneously reversed; while the movement of the driving crank is always in the same direction. It will be seen that it would not do to turn the crank itself backward and thus to reverse the rotation of the recording dials by reversing that of the barrel-pinions. This would be a simple and entirely eligible mode of proceeding if nothing were to be considered but the turning backward of the several dials through the numbers of places marked by their corresponding indexes; but as it would neutralize the whole arrangement for carrying, by making the action of the barrel-pinions to take place in the last instead of the first half of the revolution, it is inadmissible. The processes of subtraction and division now hardly require further explanation. The first of these operations requires no other manipulation but that which is used in addition. For division it is expedient, before placing the dividend, to lift the plate carrying the recording dials and to carry it as far as possible to the right. The dividend is then introduced by setting the indexes to its proper figures, and the reversing button being at *addition*, giving one turn to the crank. The button is then to be placed at *subtraction*, and the divisor marked by the indexes just beneath those left-hand figures of the dividend which suffice to contain it. The operator turning the machine watches the diminishing figures of the dividend until they become less than those of the divisor beneath them, when he ceases to turn and moves the plate carrying the dials one place to the left. In the mean time the machine itself has recorded his first quotient figure. The other quotient figures are obtained in like manner, and when the operation is complete, the remainder, if any, will stand in the place of the dividend.

The expedition with which these operations may be conducted is marvelous. It seems to be thought by some that an arithmetical machine is of no practical use, because it is not customary in point of fact to perform large multiplications or divisions by purely arithmetical processes. As computations are usually conducted, logarithms are invariably resorted to for such purposes. But these are precisely the multiplications and divisions in which logarithms, with all their utility, fail to furnish the required results without an amount of trouble-

some interpolation which it is a weariness to the calculator even to think of. No tables of logarithms extend beyond five places of natural numbers. And even those which are furnished with the auxiliary and minor tables in the same page for facilitating interpolation, exact of the most expert arithmetician a greater expenditure of time, in finding and writing the logarithms and in afterwards looking out the natural numbers, than is necessary to perform the same problem by the machine three times over. In these transcriptions and secondary computations for interpolation, there are, moreover, repeated opportunities for the intrusion of error; but the machine, when its original adjustments are correct, never makes a mistake.

In multiplying and dividing by logarithms, we often, on account of the trouble, just spoken of, of interpolation, disregard entirely the small decimals of our products, and fail to pursue our quotients to many places, and yet such neglect sometimes vitiates a result, and oftener leaves a feeling of dissatisfaction. The machine will give an answer to a number of places embracing the full extent of its range with absolutely the same facility, and with the same unerring accuracy, as to two or three only. The writer, as the result of a pretty heavy experience in the use of logarithms, and of a trial for a limited time of the calculating machine of Mr. Thomas, is fully satisfied in his own mind that, as an aid to the ordinary calculations of business, but still more to the laborious computations into which the man of science is often compelled to enter, this machine has a very substantial value, and cannot fail to be more and more highly appreciated the longer it is used.

It has been observed that the range of the ordinary calculators of Mr. Thomas is limited to six or eight places in the factors, and twelve or sixteen in the product. But it is easily seen how, with little trouble, this range may be practically extended. Suppose that, with an eight-figure instrument, it is desired to multiply two numbers extending to twice as many places; that is, to sixteen figures each. The first eight figures of the multiplicand may be treated by themselves, being assumed to have eight zeroes after them. These eight may be multiplied by the first eight of the multiplier, assumed in like manner to be followed by eight zeroes. The product, found in a few seconds, must then be written down with sixteen zeroes following; and then the same eight figures of the multiplicand may be multiplied by the second eight of the multiplier, the product being written down under the former, but with only eight zeroes. Thirdly, the second eight figures of the multiplicand may then be successively multiplied by the first eight, and the second eight of the multiplier, as before; the former product being written down with eight zeroes, and the latter with none. The four products added as they stand will furnish the total product required.

The following is an example of this kind actually performed with the machine for the express purpose of this illustration. From beginning to end, the time occupied in obtaining the result was six minutes, of

which a considerable part was occupied in transcription. Required, to multiply the number 9582653477982169 by 8795631824673912. Divide the multiplicand into 9582653400000000 and 77982169. Divide also the multiplier into 8795631800000000 and 24673912.

First product - - - - - - -	84285490973418120000000000000000
Second product - - - - - - -	2364415467181008000000000
Third product - - - - - - -	6859024454893742000000000
Fourth product - - - - - - -	1924125175475128
Total - - - - - - - - - -	84285491895762114131600175475128

Of the six minutes occupied in performing this operation, less than two are consumed in the strictly calculating part; the setting of the indexes, and the clearing of the tables between the successive multiplications requiring some time, and the transcription and summation occupying the rest. Of course a problem like this is beyond the reach of any logarithmic tables existing; and if it were not, the logarithmic method would be very much slower and greatly more troublesome.

A comparative example in which the tables will furnish by interpolation a result very nearly accurate is the multiplication of four figures by four—as for instance, 8,659 by 3,973. The machine gives the product 34,402,207 in less than half a minute, including the time occupied in preparation. It will be an expeditious operator who will reach the result by means of logarithms in less than two and a half minutes; and then he will find it inaccurate in the last place—the tables giving 34,402,208; an error which he might correct by considering the unit's places of the factors, if he could have entire faith in the truth of the preceding figures.

Of the numerous calculating machines which have been proposed or constructed since that of Mr. Thomas became an ascertained success, those of Messrs. Maurel & Jayet, of France, and of Mr. Staffel, of Russia, are the only ones which, so far as is known, have solved the problem in a manner entirely satisfactory. Both of these employ a mechanism in which the barrel pinions of Mr. Thomas are in substance introduced; and hence they cannot be regarded as presenting original solutions. In both of them the mechanism is too delicate for ordinary rough usage, and they are both costly.

It has been mentioned above that two difficulties attend the construction of a machine for arithmetical calculations. The first is to adapt it to receive any numbers within a given range on which it may be desired to operate. A counting machine adds at each movement invariably *the same* number. This is ordinarily a unit, but it may be made as well any number of units; and provided this number is to be continually added without change, no machinery is necessary to accomplish the object but such as is of the simplest description. But when the number to be operated on is different for every new operation, it is extremely difficult to devise a *simple* mechanism capable of adapting itself to this condition.

Mr. Thomas's system of barrel pinions was the earliest expedient by which the difficulty here signalized was satisfactorily overcome; and we have seen that it has been more or less explicitly reproduced in the later machines which have equally succeeded.

The other difficulty is that which is encountered when it becomes necessary to make provision for carrying for tens. In counting machines each of the figure dials acts, at the proper point in its revolution, upon the one next higher. This is the case also in the calculating machine of Musina, described above. But, in counting-machines, the addition is made always to a single dial, the lowest in order; and when it is necessary to carry from this to the next, it finds that one at rest. In an efficient calculating machine, additions are simultaneously made to all the dials; and if, in carrying, each acts directly on the next, its action will often arrive at a time when that one is in motion, so that the two actions will interfere, or the *carrying* action will fail to take effect. The only remedy, while this direct action of one dial upon another is maintained as part of the system, is to cause the dials to move successively, as in the machine of Musina; an expedient which so far protracts the time of the operation as to neutralize in great measure the advantage. The alternative is to reject the direct action of dial upon dial, and to introduce a mechanism which may be *prepared for action* at the moment when the necessity of carrying occurs; but which shall not act until all the dials have completed the movements which the setting of the machine requires. This mechanism then taking separate and subsequent effect will complete the operation. That the special branch of the problem here considered is not simple, is illustrated by the fact that, since the time of Gerbert, it has occupied ineffectually the attention of so many ingenious men; and that Babbage himself confesses that it was the source of his greatest trouble in the construction of his great difference engine.

The purpose of this engine, and of the similar machines constructed by G. Mr. Scheutz, of Stockholm, of which one is at the Dudley Observatory in this country, and another in the office of the registrar general, in London, is not to perform the simple operations of ordinary arithmetic, but to compute the extended tables required for astronomical and other purposes, in which the successive numbers form terms of a series connected by a law expressible in a general formula. The calculation of these numbers by the ordinary methods is an operation involving immense labor, and the results are liable to be vitiated by the errors to which even the most expert arithmeticians are occasionally liable. Supposing, moreover, that the computations are entirely correct, there remains the possibility of errors of the press, which the utmost vigilance is not always sufficient to prevent. It was, therefore, a part of Mr. Babbage's plan not only to compute the numbers by machinery, but also to impress them, when completed, upon a plate from which they might be directly printed, or upon a matrix from which such a plate could be cast.

The process by which the computations are made is founded on what is called in algebra the *method of differences*. It is demonstrable that, when a series of terms is calculated from a formula, by giving to a variable quantity in this formula equal successive increments, and when from these terms a series of differences is formed by taking each term from the next, and a second series, by taking the differences of the differences, and a third by operating on the second in like manner, an order of *equal* differences will be reached at last, so that the next succeeding series will be zeroes. The number of orders of differences in a purely algebraic series will be equal to the index of the highest power to which the variable is involved in the given formula. Let the formula be—

$$ax + b$$

and put $a = 2$, $b = 3$, and x (the variable) $= 0, 1, 2, 3$, &c., successively, and we have the terms,

Series - - - - - -	3	5	7	9	11	13	15	&c.
Differences - - -	2	2	2	2	2	2		

Let the formula be—

$$x^2 + ax + b$$

and we shall have two orders of differences as follows:

Series - - - - -	3	6	11	18	27	38	51	&c.
1st differences - -	3	5	7	9	11	13		
2d differences - -	2	2	2	2	2			

Take the following formula, putting $c = 4$

$$x^3 - ax^2 + bx + c$$

Series - - - - -	4	6	10	22	48	94	166	&c.
1st differences - -	2	4	12	26	46	72		
2d differences - -	2	8	14	20	26			
3d differences - -	6	6	6	6				

In like manner a series formed on the following will give four orders of differences:

$$x^4 - 2x^3 + 4x^2 - 3x + 4.$$

Series - - -	4	4	14	58	184_D	464_E	994	1894_D	3308_E.
1st differences -	0	10	44	126_C	280_d	530	900_C	1414_d	
2d differences -	10	34	82_B	154_c	250	370_B	514_c		
3d differences -	24	48_A	72_b	96	120_A	144_b			
4th differences -	24_o	24_a	24	24_o	24_a				

Suppose that in this series we had only the first five terms, ending with 184. This term we mark d, and we have a series of differences marked c, b, a, o, in an oblique downward line. As the fourth differences are all equal, we may write 24_A next after 24_o; and by the law of construction we know that this difference added to the one marked A (48) will give the difference marked b (72). Then b added to B will give c; and c added to C will give d; and finally, d added to the term D will

give E (464). Thus, by a series of four additions, we obtain any term when we have the series of differences leading up to the last term found. And as the effect of the successive additions is to carry on the successive series of differences precisely as it extends the main series, when one term has been found by this process, the extension may go on in the same way indefinitely. The letters *a*, A, *b*, B, *c*, C, &c., annexed to the differences further to the right, lead from the term 1894 to the term 3308 by the same kind of zigzag movement.

A machine, therefore, constructed to make these additions will compute any series of tabular numbers formed on such a law so soon as a sufficient number of the initial terms of the series have been computed in advance, to furnish differences of all the orders. In this case five terms are necessary. If a series has more orders of differences than four, these, in the cases which occur in practice, are very small, and rarely affect sensibly the numbers required in the tables. The engine of Scheutz employs four orders of differences, and computes the tabular numbers to fifteen or sixteen places of decimals, of which only the first eight or ten are printed. Any error from the neglect of fifth or higher differences will be lost among the neglected decimals; and when the process has been carried so far as to endanger the accuracy of the figures retained, the machine is set anew. This will only be necessary when the accumulation of fifth differences exceeds unity in the fourth.

To explain the construction of these engines without very full drawings would be impossible. The design of this notice is simply to show in what manner they effect their results by a series of additions. For each order of differences there is a distinct set of number-wheels. The numbers on the wheels belonging to fourth differences are added to those already on the wheels belonging to the third; these in turn to those of the second, and so on. Inasmuch as a wheel which is *receiving* an addition cannot at the same time be *transmitting* one, the mechanism is so contrived that the *even* differences (fourth and second) are added to the odd (third and first) by one movement, and the odd differences are carried forward by a succeeding one.

The numbers expressive of the completed term are presented in types which impress the characters in a material suitable for forming a matrix. This material is a kind of *papier maché*, such as is now extensively employed in stereotyping for the purposes of the ordinary letter-press The type are made of steel and are presented downward, the tablet carrying the plastic substance being raised at the proper moment by an eccentric to receive the impression. After each impression the tablet advances so as to present a fresh surface at the proper distance for the next impression. The entire surface of the plastic material is rubbed with black lead to give it smoothness and facilitate casting from the impression a stereotype plate of the ordinary form. When such a plate has been successfully cast the results of the computation are secured precisely as the machine gives them.

The Scheutz machine in the office of the registrar general in London has performed much useful work in the computation of tables. At the time of the Universal Exposition of 1862, in London, it was in such constant requisition that it could not be spared long enough to be made a part of the Exposition, to the interest of which it would have so greatly contributed.

Mr. Babbage has projected a calculating machine of much higher powers than the difference engine, which he calls the analytical engine. The object of this is to develop algebraic expressions and to tabulate the numerical value of complicated functions when more variables than one are made to alter their values. It is said that the designs of this engine have been prepared in detail, and Mr. Babbage himself, in his latest book, expresses a hope that it may yet be constructed; but the undertaking is, in a pecuniary point of view, a formidable one, and there is reason to apprehend that he may be disappointed.

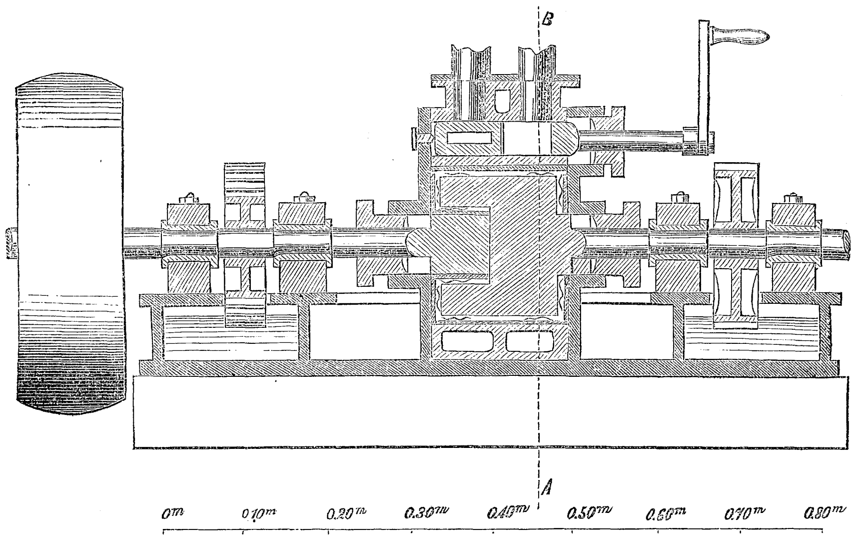
ADDENDA.

ESTIMATED VALUE OF ATMOSPHERIC PRESSURE.

In the calculations of pressures, on page 80, the pressure of the natural atmosphere is taken at 2116.8 pounds per square foot. If we assume, as is commonly done, the mean atmospheric pressure to be 15 pounds per square inch, the pressure per square foot will be 2160 pounds. It is nearer to the truth to take the mean pressure at 14.7 pounds; and it is upon this assumption that the determination is made for the purpose of the calculations above referred to. This statement was appended in the original manuscript to the passage on page 80, and was designed to appear on that page as a foot-note; but the note was accidentally omitted.

THOMPSON'S ROTARY STEAM-ENGINE.

In the description of Thompson's differential rotary steam-engine, commencing on page 87, it is remarked that "it will be seen by comparing these figures that there are two pairs of pistons, each pair being attached to a core which occupies but half the length of the cylinder in the direction of the axis." The comparison of the figures given does not illustrate the last part of this statement; and the reason of the disagreement between the description and illustration is, that one of the wood-cuts designed for insertion in that place, having been accidentally



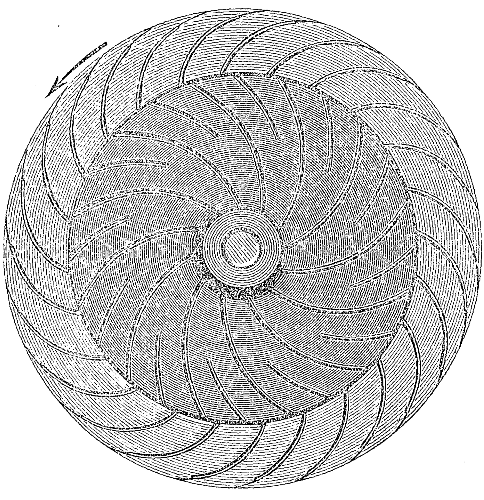
mislaid, was omitted. This cut is here supplied. It represents the engine in elevation, with a longitudinal section of the cylinder, and of the elliptical gear-wheels which are directly driven by the pistons. One of the pairs of pistons is seen in complete section, attached to a core which

occupies but half the length of the cylinder. The other pair is out of the plane of the section, but the section of its central core is presented. This figure shows also, in longitudinal section, the cylindrical valve exhibited in cross-section in Fig. 16, and referred to on page 93. The position of this valve, as shown here and in Fig. 16, is that in which the steam is shut off. The engine is started by turning the crank forty-five degrees to the right or to the left. If it be turned to the left, the steam will enter and leave the engine in the direction of the arrows in Fig. 16, and the rotation will be from left to right. If turned in the contrary direction, the rotation will be from right to left. The shaft which carries the pulley is directly behind the piston shafts.

In the equation in line 14 of page 91, relating to this engine, there is some error of spacing which may create a little confusion, but a comparison of the equation with the preceding proposition will readily suggest the necessary correction.

FOURNEYRON'S TURBINE WHEEL.

The description of the Fourneyron turbine wheel, on page 110, was accompanied in the original by a drawing, showing the relation of the directrices of the issuing water to the floats of the wheel; but this unfortunately was not at hand when the pages were made up for the press, and it was accordingly omitted.



The figure is not, perhaps, necessary to the intelligibility of the description; but as it has since presented itself, it is here subjoined. In this figure the interior and deeply shaded part represents the base of the closed cylinder containing the volume of water. The exterior annulus, shaded more lightly, is the outer portion of the wheel carrying the floats. The axis of the wheel is seen in projection in the center, surrounded by the protecting cylinder which keeps it free from the water. The directrices, which are fixed firmly within the water cylinder at the base, are represented by lines curving from right to left, while the floats have a contrary curvature; so that, at the several points of intersection, the tangents of the respective curves are nearly at right angles to each other. Each alternate directrix extends from the central to the exterior cylinder. The intermediate ones have less than half the length. It is obvious that, with the arrangement represented, the rotation of the wheel will be from right to left, in the direction indicated by the arrow.

ERRATA.

Some errors have, unfortunately, crept into the impression of the foregoing report. Only such are here noticed as are likely to mislead:

Page 30, line 13 from top, for BCC′B read BCC′B′.

Page 35, line 36 from top, for A and B, read A and C.

Page 44, line 32 from top, for 360.98 read 370,980.

Page 45, line 5 from top, for maximum density, read density at maximum temperature.

Page 45, line 5 from top, for minimum, read atmospheric.

And in the analysis which follows, for AL read *al*, and *v. v.* throughout.

Page 47, line 3 from top, for 450° read 482°.

Page 52, line 28 from top, for can run, read can be run.

Page 62, line 3 from bottom, for twofold, read something over.

Page 94, line 10 from bottom, for *a* read *u*.

Page 111, line 11 from top, insert "equal" before "cells," and omit the remainder of the sentence.

Page 115, in legend of cut, for containing read controlling.

Page 133, line 6 from bottom, for two read twelve.

Page 137, line 18 from top, for 1837 read 1857.

Page 138, line 2 from top, for one one-hundred-and-sixty-fifth, read one six-hundred-and-thirty-fifth.

Page 146, line 3 of note, insert $\div 1500$ in first member of equation.

Page 146, line 5 from bottom, 1st formula,
Page 146, line 6 from bottom, 2d formula,
Page 146, line 9 from bottom, 2d formula,
reverse the indices 0 and 1 of letters within the brackets.

Page 149, line 17 from bottom, for thirty-six read fifty-six.

Page 156, line 4 from bottom, for *m* read *p*.

Page 158, line 11 from top, for $\times$ read $+$.

Page 158, line 29 from top, for 3,922 read 3,939.

Page 159, line 7 from bottom, for two read four.

Page 174, line 7 from top, for volume read column.

Page 178, line 2 from top, for centre read circle.

Page 189, line 10 from bottom, for E read B.

Page 192, line 9 from bottom, for at read to.

Page 222, line 14 from top, for G read *a*.

Page 402.—The note on this page belongs on page 395.

Page 465, line 10 from top, for copper read silver.

Page 477, line 3 from bottom, for $N = n\,2v = n2r^1$ read $N = n2^v = n2^{r-1}$.

Page 494, line 18 from bottom, for $dn : Dn$ read $d^n : D^n$.

Page 510, line 4 from top, for synchronous read isochronous.

Page 581, line 17 from bottom, for F' read $F_{,}$.

Page 620, line 5 from top, for one three-thousandth read three one-thousandths.

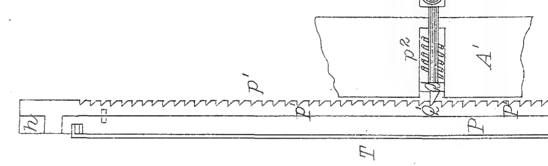


Fig. 4.

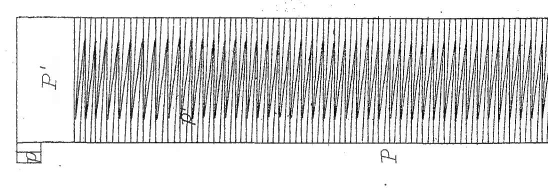


Fig. 3.

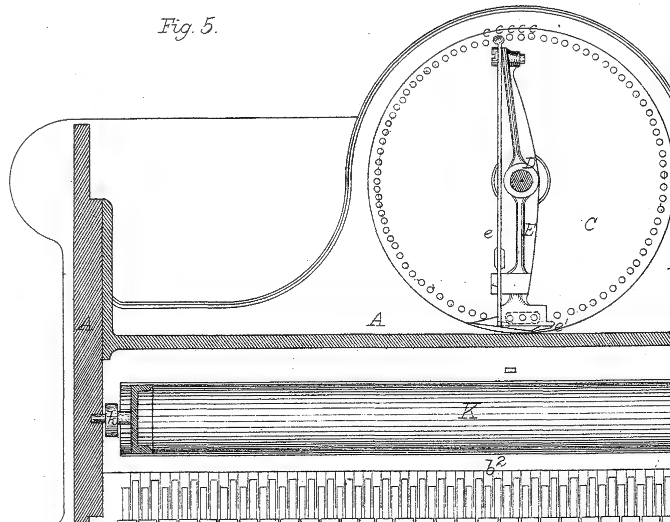
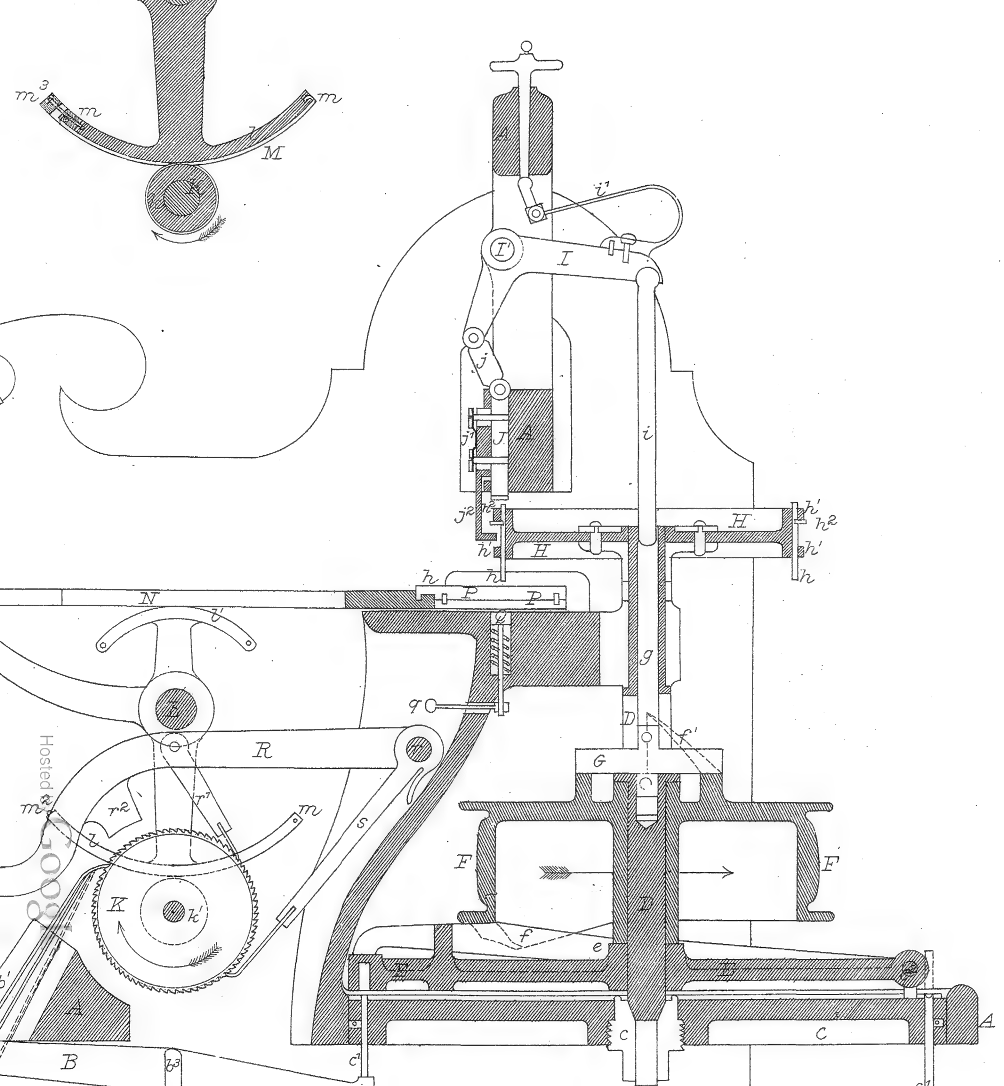
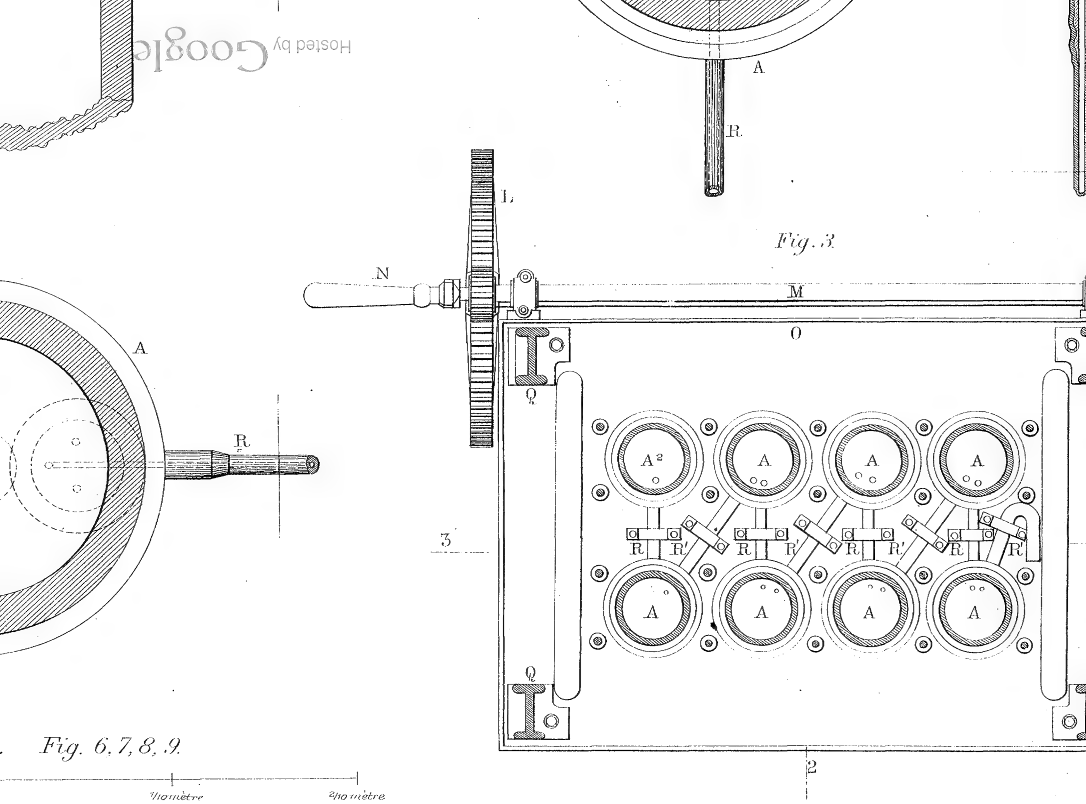
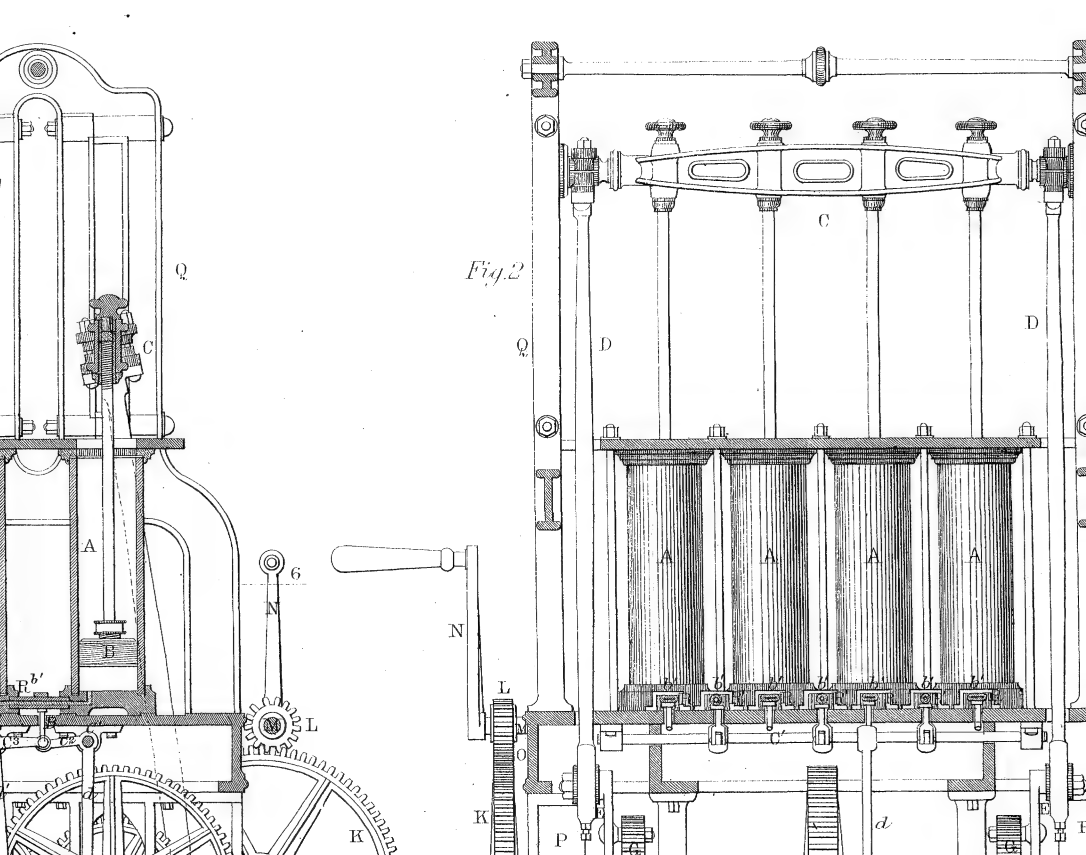


Fig. 5.





RICHARD'S AIR-PUMP.



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